KENYA FORESTRY RESEARCH INSTITUTE

CONTRIBUTION OF FORESTRY RESEARCH TO SUSTAINABLE DEVELOPMENT

Proceedings of 5th KEFRI Scientific Conference

17 – 19 April 2018

at KEFRI Headquarters Muguga

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NOVEMBER, 2018

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Cover caption:
Aerial view of KEFRI Headquarters Muguga.

Citation:
Chagala–Odera E., Ochieng D., Wanjiku J., Muchiri M.N., Gichora M., Tuwei P., Kamondo B., Mengich E., Langat D., Oballa P., Muthike G., Chiteva R., Kagombe J., Cherotich L., Gathogo M., Muthama A. and Oduor N. (Eds). 2018. 'Contribution of Forestry Research to Sustainable Development': Proceedings of 5th KEFRI Scientific Conference, 17 – 19 April 2018 at KEFRI Headquarters Muguga. KEFRI, Kenya.

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Published by:
Kenya Forestry Research Institute
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Layout and design: Dorothy Ochieng

Printed by: Fiesta Works

Foreword

Kenya Forestry Research Institute (KEFRI) is a state corporation mandated to: Conduct research in forestry and allied natural resources; Disseminate research findings; and Establish partnerships with relevant institutions and organizations. To fulfil this mandate, KEFRI undertakes various activities including holding of scientific conferences whose main aim is to share research results for evaluation or application by stakeholders. The 5th KEFRI Scientific Conference was held from 17th to 19th April 2018. The Conference was organized to bring together key actors in forestry research and development in Kenya and the region, to discuss recent advances in forestry research and technology in the face of: climate change; increased demand for forestry products and services; and increasing environmental degradation.

The theme of the Conference was 'Contribution of Forestry Research to Sustainable Development' with six sub-themes namely: Forest Productivity and Improvement; Biodiversity and Environment Management; Socio-Economics, Policy and Governance; Forest Products Development; Information and Knowledge Management; and Partnerships, Networks and Resource Mobilization. Consistent with the sub-themes, the Conference in its deliberations also discussed advances in forestry research and technology in the context of the Government Big Four agenda namely: Food security, Manufacturing, Affordable housing and Universal health care. Proceedings of the Conference succinctly present technologies and information in forestry and allied natural resources that have been generated through research, and how they can be leveraged to deliver the Government Big Four agenda. Although the Conference Proceedings highlight major milestones that have been achieved in forestry research, it is clear that many challenges facing forestry development in the country require to be addressed, necessitating increased investment in forestry research in terms of human and capital endowments. KEFRI will however continue to work with all stakeholders including forestry managers, tree growers, wood processors, and farmers, to ensure that the technologies are widely adopted to impact on forestry development and the Government Big Four agenda, to enhance socio-economic transformative changes in the country.

KEFRI is grateful to the Government of Kenya which provided the bulk of the resources used in organizing and holding the Conference, and producing the Proceedings. KEFRI also recognizes contribution of its Partners who continue to support the Institute with funds to undertake research whose results were presented in the Conference. I wish to also take this opportunity to appreciate the Conference Organizing Committee, keynote speakers, session chairs, rapporteurs, presenters of various papers, participants and all other persons who in one way or another contributed to the making the Conference a success.

Jane W. Njuguna (PhD)
Ag. Director, Kenya Forestry Research Institute

OPENING

SESSION

Speech for KEFRI Board of Directors by Mr. Robinson Ng'ethe During the Opening of 5th KEFRI Scientific Conference at KEFRI Headquarters, Nairobi - Kenya, on 17th April 2018

Cabinet Secretary Ministry of Environment and Forestry, Mr. Keriako Tobiko
Chief Administrative Secretary Ministry of Environemt and Forestry, Hon. Mohammed Elmi
My Colleagues in the Board
Representative of the Chief Conservator of Forests
Founding Director of KEFRI, Dr. Jeff Odera
Second Director of KEFRI, Dr. Paul Konuche
Distinguished Guests
All protocols observed

On behalf of the KEFRI Board of Directors and my own behalf, I would like to welcome you to this Conference. It gives me great pleasure to be part of this forum which gives the country a chance to evaluate the incremental gains achieved in forestry research in the past decade.

Forests and forest products touch every part of our lives. Forestry research, therefore, remains a core priority area for the country. KEFRI is mandated to: Conduct research in forestry and allied natural resources; Disseminate research findings; and Establish partnerships and cooperate with other research organizations and institutions of higher learning in joint research and training. In fulfilling its mandate, KEFRI supports implementation of the Ministry of Environment and Forestry agenda on protection, conservation and development of environment and natural resources for sustainable development. To achieve its mandate, KEFRI operations are guided by five-year strategic plans. The current Strategic Plan 2013 – 2018 is aligned to Vision 2030, Constitution of Kenya 2010, the National Forest Programme (2016-2030) and other relevent national policies, as well as regional and international initiaves.

Distinguished Guests Ladies and Gentlemen
The Institute in the current strategic plan is implementing its research agenda through five thematic areas namely: Forestry Productivity and Improvement; Forest Biodiversity and Environment Management; Socio-economics, Policy and Governance; Forest Products Development; and Technical Support Services. The Institute has decentralized its research activities into eco-regional and national programmes, which cover the country taking into account uniqueness of each eco-region, natural resource challenges and socio-economic and livelihood status of local communities.

We are grateful that the Government finances about 80 percent of KEFRIs research and development budget. We also recognize that we have received additional financial support from both local and international partners. I particularly would like to recognize the Japan International Cooperation Agency (JICA), a long term partner in technical cooperation and Third Country Training Programme, European Union (EU), which is supporting the WaTER

Towers Programme, World Bank Kenya supporting Kenya Coast Development Project (KCDP), Adaptation Fund, and Green Economy Partnership (GEP), among others that I may not have mentioned - please consider it included.

Distinguished Guests Ladies and Gentlemen,
KEFRI is ISO 9001:2015 QMS certified. The standard ensures that the Institute conforms to international standards of environmental management, timely delivery of quality products and services, as well as meet legal and statutory obligations.

Finally, I wish to urge KEFRI scientists to keep up the excellent research work and continue disseminating research findings and technologies to the stakeholders.

Thank you

Speech by the Acting Director KEFRI, Dr. Jane Njuguna During the Opening Ceremony of the 5th KEFRI Scientific Conference at KEFRI Headquarters, Nairobi - Kenya, 17th April 2018

Cabinet Secretary Ministry for Environment and Forestry, Mr. KeriakoTobiko
Chief Administrative Secretary Ministry of Environemt and Forestry Hon. Mohammed Elmi
Chairman of KEFRI Board of Directors
Members of KEFRI Board of Directors
Representatives from CABI, EU, NaFFORI
Former KEFRI Directors
Conference Participants
Distinguished Guests
Ladies and Gentlemen

On behalf of the Conference Organizing Committee and my own behalf, I feel honoured to welcome you to the 5th KEFRI Scientific Conference.

The Conference brings together professionals from the forestry sector, research institutions, national authorities, county governments, institutions of higher learning, key representatives of multilateral organizations, private sector and tree growers among others, to exchange scientific knowledge relevant to forestry and allied natural resources for socio- economic development.

Distinguished Ladies and Gentlemen
The mandate of KEFRI is to: develop technologies, innovations and information in forestry and allied natural resources; Disseminate information; and Establish and strengthen strategic linkages and partnerships and corporate with other research organizations and institutions of higher learning in joint research and training to promote socio-economic development.

This Conference therefore will present past and prevailing research initiatives undertaken by KEFRI and collaborating institutions towards achieving sustainable management and conservation of the country's forest resources and allied natural resources. Among the key issues the participants will deliberate on are: the contribution of forestry science to sustainable management of natural resources, forestry value chain and forestry issues to address the Government Big Four agenda of Increasing food security, Manufacturing, Universal health care, Affordable housing; and of course employment for the youth.

We have amongst us young scientists who are increasingly becoming key players in forestry sector. Beside scientists, we also recognize the Kenya Forest Service, Kenya Agricultural and Livestock Research Organization, Kenya Marine and Fisheries Research Institute, NetFund, CIFOR, BioIN, Kenya Plant Health Inspectorate Service, European Union, JICA, Institutions of higher learning, the private sector, tree growers and other partners and collaborators represented here. These clients and collaborators contribute positively to environmental conservation through tree planting and other activities.

In welcoming you to KEFRI, I would like to inform you that the Institute remains committed to its vision of being a centre of excellence in forestry research in the region. The current 5th Strategic Plan is structured into five thematic areas that include: Forest Productivity and Improvement; Forest Biodiversity and Environment Management, Socio-economics, Policy and Governance; Forest Products Development; and Technical Support Services.

Research implementation is undertaken in five Eco-region research programmes and 1 national research programme with the main centres at: Gede, Kitui Muguga, Londiani, Maseno andKarura respectively; sub-centres at Nyeri, Kakamega, Turbo, Turkana, Kibwezi; and field centres at Kuja River, Ramogi, Marigat, Bura, Lamu, Wundanyi, and Migori.

Ladies and Gentlemen,
Various papers will be presented during the Conference, of which we expect increased awareness of research findings and opportunities in forestry development. We also believe that linkages among all sectors in forestry development will be strengthened. I am confident that the 5th KEFRI Scientific Conference will disseminate important findings for immediate application in the development of forestry and related resources in our country and the region.

Finally, I sincerely thank the Ministry of Environment and Forestry for continued support through timely release of funds for research and operations. Additional support to hold this Conference has been received from the National Research Fund and I take this opportunity to express our appreciation for their generous contribution.

With these remarks, I once again welcome you all to this Conference and I look forward to fruitful discussions.

Thank you

Opening Speech by the Cabinet Secretary Ministry of Environment and Forestry, Mr. KeriakoTobiko (MBS, SC) During the Opening Ceremony of 5th KEFRI Scientific Conference at KEFRI Headquarters, Nairobi - Kenya, 17th April 2018

Chief Administrative Secretary Ministry of Environment and Forestry, Hon. Mohammed Elmi
The Chairman KEFRI Board of Directors
Members of KEFRI Board of Directors
Acting Director KEFRI
Former Directors of KEFRI, Dr. Jeff Odera and Dr. Paul Konuche
Representatives of EU, JICA and other partners,
Scientists gathered here
Ladies and Gentlemen

Hamjambo, Hamjambo Tena, Tukopamoja, tukifanya nini? Tukifanya kazi.

Scientists, employees, and government officials belong to different worlds, but today we are united by one common goal. I am extremely pleased to be invited to participate at this auspicious occasion of the 5th KEFRI Scientific Conference. I most sincerely thank the organizers for the invitation. I am informed that KEFRI is expected to hold a Scientific Conference after every 4 years. I note that the last one was held in 2008 at this venue. I appreciate that the failure to adhere to the schedule was due to the challenge of resources.

This county, and probably other developing countries have this tragedy where scientists in Public Service retire at 55 to 60 years of age, when their knowledge has just ripened. This is demonstrated by the energy and vigour we have witnessed in Dr. Odera who retired as KEFRI Director over twenty years ago. No doubt, Dr. Odera is not an isolated case, as there are many others. When we ignore these distinguished scientists, there are many organizations and countries that quickly engage them to serve outside the country and we would then complain of brain drain. We need to think seriously about the premature retirement of our best scientific brains at 55 to 60 years of age. Nonetheless, nothing has prohibited the Ministry from forming a panel of distinguished personnel both local and international to be occasionally consulted. Another critical matter that we should look through is personnel succession planning and management. When, I look around in my Ministry and other institutions in Public Service there is a huge gap. The top cadres are heavy and I do not have enough experienced staff to succeed those retiring in the near future. So there is need for personnel succession planning and management.

The 5th KEFRI Scientific Conference theme, "Contribution of Forestry Research to Sustainable Development" is both topical and timely, and most opportune, as we are aware of what this country is going through pertaining to forestry and environmental conservation. The economic blue print, Kenya Vision 2030, now running into its third implementation phase, outlines broadly the expected outputs of environment management including forestry and biodiversity. We are looking at you, the scientists to assist us in meeting government development agenda by providing technologies and information for achieving the targets of Kenya Vision 2030 and the Government Big Four agenda namely: Food security, Universal health care, Manufacturing, and Affordable housing.

Last week, I attended an international forum on climate change and one of the issues discussed was the implementation of nationally determined contributions (NDCs). All the countries, about 170 presented their NDCs. The total cumulative effect of all those NDCs would reduce the global average temperature by at most 3^oC, because, as you all know continued increase in temperature would lead to calamity, resulting in extinction of some of the species and will threaten human life. The global target of NDCs is 1.5^oC and I am hoping that adoption of presentations and proceedings of this Conference will contribute to achieving this target.

Now coming back home, all of us know that our Constitution threshold for forest cover is 10%, which is internationally prescribed. We are informed that our forest cover is 7.2 %. Is it true or not? I am raising this because the country lacks empirical data. There is therefore need to provide data of our country's forest resources. The data would be the benchmark to determine if the country will meet the target of 10% forest cover by year 2030. However, we should not wait to achieve the target by 2030 as the Leadership (The President and The Deputy President) has decreed that we achieve the target by the year 2022. We must therefore plan how to achieve the target within the time frame. The decision is political and we must implement it. Again, our Government has isolated the Government Big Four development agenda, namely food security, universal health care, manufacturing and affordable housing. I believe the persons gathered here will provide scientific input towards attainment of the agenda. Therefore, at the end of the Conference, I urge KEFRI to review the deliberations and the papers presented to isolate technologies and information that will immediately start contributing to the development of the Government Big Four agenda. The Conference Proceedings should also be published and distributed as soon as possible in order to benefit consumers of information.

Ladies and Gentlemen
I have a reason to stay here throughout the Conference and in particular to isolate technologies and information that supports the Government Big four development agenda, but I will not be able to because of urgent matters that I have to attend to. However, my humble request is that the Conference participants ensure that they have planted at least 200 trees before they leave, as a good gesture to support the ongoing tree planting activities in the country.

Ladies and Gentlemen
I thank you all and the Conference Organizing Committee for inviting me to preside over this gracious occasion. It is now my pleasure to formally declare this 5th KEFRI Scientific Conference officially opened and again, thank you all very much.

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Executive Summary

The National Forest Programme (2016-2030) has set the agenda for the development and coordination of forestry sector to meet the needs of Kenyans based on the Constitutional values and principles of Vision 2030, with the aim of moving the country to a middle-income industrial status. It is within this framework that the 5th KEFRI Scientific Conference was held to bring forward the recently developed technologies and innovations, as well as information to contribute to sustainable forestry development. The theme of Conference was "Contribution of Forestry Research to Sustainable Development" and the objective was to provide a platform for exchange of scientific knowledge and technologies relevant to forestry and allied natural resources. The Conference covered the following themes: Forest Productivity and Improvement; Forest Biodiversity and Environment Management; Socio-economics, Policy and Governance; Forest Products Development; Information and Knowledge Management; and Partnerships, Networks and Resource Mobilization. Key challenges that may hamper the development of forestry sector were also identified and discussed.

Forestry Sector plays a vital role in soci0-economic development, supports agriculture, tourism and energy sectors, and is crucial in mitigation against climate change. To enhance these roles, more effort is required specifically in the management and conservation of forests and allied natural resources, to secure a clean and healthy environment and increase the county's forest cover to at least 10 percent of the total land area by 2022. Among the key issues the participants discussed were the contribution of forestry research to gross domestic product, environment and policy issues to address the Government's initiative of increasing employment opportunities for the youth and the Big Four agenda of food security, manufacturing, universal health and affordable housing.

The Conference was attended by 224 participants from 29 organizations comprising of researchers, dons, managers, policy makers, farmers, students and many other stakeholders in the forestry sector. During the Conference, a total of 62 oral papers and 18 posters were presented, the contents of which elucidate technologies, innovations and information for enhancing development of forests and allied natural resources, the environment and livelihoods. The key topics covered were on conservation and rehabilitation of degraded forests, especially the major water towers; establishment and enhancement of productivity in forest plantations; sustainable utilization of forest resources, and initiatives to support climate change adaptation and mitigation. Technologies and information to support conservation of threatened species including Sandalwood (*Osyris lanceolata*), and other species valued for commercial timber, woodfuel and medicine, as well asthe safe movement of germplasm were also presented.

The Conference was held when uncertainties about the future of Kenyas forests were of great concern. Key among the challenges is the decreasing forest cover aggravated by illegal logging and encroachment for settlement and developmental initiatives. The increasing incidences of disease and pest outbreaks is also worrying, while the continued depletion of forests is leading to catastrophic environmental issues including soil erosion, flooding, desertification, water shortage and poor water quality. It has also resulted in conflicts and untold suffering that threaten the very survival of life. In addition, there are global concerns resulting from loss of biodiversity, and increased carbon emissions. These issues present great challenges to the scientific community, consumers and policy makers and are expected to guarantee safer and sustainable resource utilization.

The wide perspective for the future research and forestry was set by a Keynote paper by Dr. Jeff A. Odera, Founding Director of KEFRI and the Opening Speech by Cabinet Secretary, Ministry of Environment and Forestry, Mr. Keriako Tobiko. The presentations emphasized the need for a deeper understanding of research processes to be more inclusive and the Government Big Four agenda as the basis for setting development targets, hence the need for effective dissemination of research outputs based on strong partnerships. The participants unanimously took more time to reflect on the bigger picture on policy directions to shape Government Development Plans from the year 2018 to 2022.

To increase scientific research output, it was evident from the Conference that there is need to encourage multi-disciplinary research guided by good management, guard intellectual property rights, conduct regular monitoring and evaluation and field research audits on overall performance. This would include tracer studies on technology adoption and performance. It is imperative that scientists should revisit the production and dissemination of forest technical and management orders to facilitate adoption of technologies. There should be a deliberate effort to promote development and use of research protocols to enhance replication and up-scaling of successful achievements of research.

The Conference was informed that conservation of biodiversity and environmental management will mainly be achieved through ecosystem based monitoring with participatory planning. The buffering effect of farm forestry and social forestry technologies in biodiversity conservation and management were also emphasized, which leads to increased tree products and services, thus releasing pressure on natural forests. The two types of forestry can gradually provide biomass energy and other products for domestic and industrial uses. Such technologies through research moderation should be replicated in other agro-ecological zones, especially in arid and semi-arid areas. Research in riparian and mangrove vegetation should also be prioritized with respect to regulatory services they provide, hence making a contribution to the blue economy. Gender roles and socio-economic status should be taken into considerations for balanced development.

The main issues discussed in the area of forest productivity and tree improvement revolved around quality seed production, certification, distribution and marketing. The Conference was informed that there is a growing demand for certified seed for the establishment of industrial plantations and other planted forests. Research in the improvement of indigenous tree species was also highlighted with emphasis on continuous monitoring of trials and permanent sample plots (PSPs). The establishment of seed stands and seed orchards for quality seed production was stressed as a key mandate for KEFRI that requires revamping through research in tree genetics, breeding and biotechnology. Similarly, the forest seed production systems also require strengthening on quality seed collection, processing, storage and distribution. It was noted that such improvement will involve acquisition and maintenance of seed production equipment. Regional Research Programmes should be mandated to distribute seeds to meet the growing demand. KEFRI was also challenged to move forward and enhance distribution of quality tree seeds through private sector, but must take charge of certification of forest seed and licensing of suppliers.

During discussions on Forest Products and Development, it become clear that there is need for more research on alternative green energy sources and efficiency in energy production and use. Further research should be directed to timber processing and bamboo research for housing, manufacturing and food security, and the underutilized indigenous fruit trees and medicinal plants that will enhance food security and universal health care. Most of these can be linked to the great potential that lies in undestanding indigenous knowledge systems especially with respect to non-wood forest products. It is imperative that the contribution of forestry through regulatory services is studied to determine the total value of forestry enterprises to the national economy. There is need to develop equitable Payment for Ecosystem Services (PES) schemes to fit with Intergovernental Panel on Climate Change (IPCC) guidelines for trade in ecosystem services derived from conservation efforts. This can be extended to rehabilitation of degraded mangrove areas for carbon emission capture, and highlight the need for forestry research and subsequently, budgetary support.

Involvement of many stakeholders in the forestry sector activities was identified as key to creating synergies in research in cross cutting themes such as socioeconomics, policy, governance and climate change. The approach will lead to integration of Indigenous Knowledge Systems in the formulation of ecosystem management plans, land tenure and property rights, which will assist to unlock the potential of the underutilized forestry resources. Livelihood improvement schemes among pastoralists in Arid and Semi-Arid Lands (ASALs) are on-going examples of such arrangements that are unlocking the potential of forestry in marginalized areas. There is constant need to review, monitor and evaluate forest governance at local levels through Community Forest Associations (CFAs) and other actors to enhance capacity building for forest research and management.

Knowledge Management and Partnerships were isolated as critical steps for forestry research management. Areas of focus include: strengthening the capacity of Counties for forestry extension services, joint establishment of demonstrations and organization of field days, development of efficient and effective research communication strategies, training needs assessment, packaging of forest sector for viable investment and enacting of subsidiary legislation for implementation of Public Private Partnerships (PPPs).

THEME 1: FOREST PRODUCTIVITY AND IMPROVEMENT (FPI)

Tree climber demonstrating seed collection method

Growth Performance of Second Generation *Pinus maximinoi* and *P. tecunumanii* Progeny Trials at Turbo, Kenya

Atie W.O.*, Mbinga J., Cherono F., Omondi S., Bala P., Muchiri M.N. and Chagala-Odera E.

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Abstract

Pines are planted for soft wood timber, pulp, fuel wood and resin production in Kenya. In the highlands, the common species are *Pinus patula* and *P. radiata*. *Pinus patula* is the most widespread while *P. radiata* is rarely being planted due to attack by diseases. Therefore, in order to broaden the pine species diversity in the higher elevation areas of Kenya, provenances-progeny trials of *Pinus maximinoi* H.E. Moore and *Pinus tecunumanii* J.P. Perry families were established at Turbo Forestry Research station in May, 2011. The seed were supplied by the Central American and Mexico Coniferous Resources (CAMCORE) Cooperative in a collaborative project between KEFRI and other partners. A total of eighteen (18) and thirty three (33) families of *P. maximinoi* and *P. tecunumanii*, respectively were planted and are being monitored. The test design for *P. maximinoi* is 5 replicates consisting 4-tree line plots, and for *P. tecunumanii* is 6 replicates of 4-tree line plots. These families are being tested against local *P. patula* that has adapted to the local conditions of the area. The parameters assessed are survival rate, height, dhh and juvenile tree volume. Early establishment assessments indicate that most of the families of both *P. maximinoi* and *P. tecunumanii* had good survival rates with a mean of 89.2 % for *P. maximinoi* and 78.7% for *P. tecunumanii*. The survival for the local *P. patula* remained constant at a mean of 78.5 %. Comparing general growth 5 years after planting there were significant differences ($P \leq 0.05$) among the families of *P. maximinoi* in all the parameters assessed. Family 863 of *P. maximinoi* had the greatest mean height of 10.7 m while family No. 691 had the lowest height growth of 8.1 m. There were no major significant differences among the families of *P. tecunumanii* families at age 5 years in height, dbh and juvenile tree volume assessed. But family No. 2358 had a better height growth of 8.7 m compared to the low height of 6.7 m attained by family No. 93. The local *P. patula* had a mean height of 7.8 m, diameter at breast height of 10.13 cm and mean juvenile tree volume of 0.0157 m^3. Family No. 2342 of *P. tecunumanii* had the best dhb growth of 12.90 cm and juvenile volume of 0.0369 m^3. It is concluded that early growth rate of *P. maximinoi* and *P. tecunumanii* is better than that of the widely grown *P. patula* in the highlands of Kenya.

Keywords: Families, *Pinus maximinoi*, *Pinus tecunumanii*, progenies

Introduction

Pinus species are some of the key commercial tree species planted for soft wood timber and pulp production in Kenya. The most common species in the highlands are *Pinus patula* and *P. radiata*. Planting of *P. radiata* have been hampered by disease attack. To broaden the pine species in the higher elevations, *Pinus maximinoi* H.E. Moore, *Pinus tecunumanii* J.P. Perry and other pine hybrids are being tested in a field experiment at the Turbo Forestry Research Station.

Pinus maximinoi, commonly known as thin leaf pine is found in El Salvador, Guatemala, and Mexico at elevations of 1,500–2,400 m and is a fast-growing reaching a height of 20–40 m and diameter at breast height (dbh) of 40 to 100 cm with a smooth bark when young (Carbajal and McVaugh, 1992, Lopez-Upton and Donahue, 2002). The wood of *P. maximinoi* is soft and light; the sapwood is pale yellowish white, and the heartwood is slightly darker (Perry, 1991). Specific density in trials in Colombia varied from 0.32 to 0.51 and in South Africa from 0.49 to 0.50 (Kietza, 1988; Wright and Baylis, 1993; Wright and Osorio, 1993; Wright and Wessels, 1992). Its potential uses include paper, firewood, resin extracts, and sawn timbers for roof supports and doorways (Wright and Wessels, 1991; Dvorak *et al.*, 2000). Due to its multiple uses and good performance in other parts of the world, the species was identified for introduction in Kenya.

Pinus tecunumanii (syn. *Pinus oocarpa* var. *ochoterenae* Martínez; *Pinus patula* Schiede & Deppe spp. *tecunumanii* Eguiluz & Perry) is a timber species native to Mexico and Central America. It grows from the highlands of Chiapas and Oaxaca to Northern Nicaragua (17° to 14° North latitude). It occurs in two separated populations in their native habitats. High altitude group grows at 1500-2900 m and low altitude group from 500-1500 m. Mature trees of *P. tecunumanii* in high altitudes can reach 55 m in height and more than 100 cm in dbh (Dvorak, 1986; Dvorak *et al.*, 2000). Its small crown and its thick, gray, furrowed bark near the base with thin, gray, flaky barks higher easily recognize the tree on the stem. It has a very straight stem form, small cones borne in ones and twos on long, thin peduncles, and needles in fascicles of mainly four (Falkenhagen, 1990). It has been cultivated in several sub-tropical parts of the world for paper industry and cultivation trials have shown that high elevation sources are the most productive (Dvorak, 1986). It grows well in Colombia, Venezuela, Brazil and South Africa.

Pinus tecunumanii has a yellowish wood much like some of the southern pines from the United States. In natural stands, trees that average at least 30 years old have wood density that ranges from 0.510 g/cm^3 to 0.560 g/cm^3 (Dvorak, 2002; Eguiluz and Zobel, 1986). In Mexico and Central America the wood is used for sawn timber, framing, pallets, broomsticks, fuel wood, and kindling for fires.

Trial plots were established using the above two species which are still not well adopted in Kenyan plantations. The objective of this study is to test the suitability of various progenies of *P. maximinoi* and *P. tecunumanii* at Turbo Forestry Research Station, Kenya.

Materials and Method

Planting materials

Seeds comprising of 42 and 41 families of *P. maximinoi* and *P. tecunumanii* of respectively were received from CAMCORE (Central American and Mexico Coniferous Resources Cooperative) for establishment of the trials in Kenya. The seed were pre-treated by soaking in tap water at room temperature of 20 ± 2^0C for 24 hours before sowing. They were sawn in loosened soil collected under pine plantation mixed with river sand at a ratio of 1:1 and covered with a thin layer of the mixture (about 0.5 to 1.0 cm). Seeds were sown in a manner that the family numbers could be identified separately. The sowing was done in a glass house set at room temperature of 20 ± 2^0C in Kenya Forestry Research Institute (KEFRI) headquarters - Muguga and watering done after every two days. The seedlings were pricked out in the glass house after 3 weeks and transplanted into 10 by 15cm tubes containing soils collected under pine plantation. The tubes were labeled with the family numbers (provenance) to keep the identity of the seed sources. The seedlings were then removed from the glass house after two weeks of pricking out into nursery shade and watering was done after every two days until they were transferred for planting in Turbo. It is important to note that not all the seeds from the different families germinated to produce required number of seedlings needed for the trials. Therefore only families that produced enough seedlings were included in the field trials.

Study site

Pinus maximinoi and *P. tecunumanii* progeny trials were established in May, 2011 at Turbo Forestry Research in Kakamega County. The experimental site lies at 035°3′ 45.62″ E and 0°38′ 2.265″ N at an altitude of about 1859 m above sea level with a mean annual temperature of 18.3 °C. The mean annual rainfall is approximately 1500 mm and is received between the months of May and September each year. The soils are dark brown, clay-loam with moderate drainage, pH ($Cacl_2$) =4.4, low Org.C =1.31 % and phosphorus Pppm=6.53, nitrogen = 0.18 % and potassium Kppm=376.3.

Land preparation and establishment

The experiments were established in a plot previously planted with *Pinus patula* until the year 2002 when the mature trees were clear felled. The area stayed fallow for a period of about 10 years with only natural vegetation of scattered *Acacia mearnsii* and bushes growing. Naturally growing trees were uprooted and the area ploughed and harrowed using a tractor. Soil samples were collected within the prepared plots before establishment for laboratory analysis to determine the physical-chemical characteristics of the soil. After land preparation, seedlings of *P. maximinoi* and *P. tecunumanii* were planted in marked plots at a pacing of 3 m x 3 m.

The experimental design varied for the two species. *Pinus tecunumanii* progeny (33 families + local *P. patula*) were planted in 4-tree line plots and replicated six times, and each replicate contains 30 sub-plots (entries). On the other hand, *Pinus maximinoi* (18 families + local *P. patula*) progeny was also planted in a 4-tree line plots but with five replicates and each replicate has 14 entries. It's important to note that some families had less than five replicates because the affected families had fewer seedlings during time of establishment. The local *P. patula* seedlings from Turbo forest tree nursery were used as the control for both the trials. Replacement of the dead seedlings was done within one month after planting. The trials were assessed for 5 years and the data for the fifth year applied to compare growth performance in terms of survival (physical counts), height and DBH (1.3 m above the ground). Stem volume for individual trees was estimated using the following equation for juvenile trees (Ladrach and Mazuera 1978):

$$V = 0.00003\ (\mathrm{DBH}^2 * H).$$

Where, V is the individual tree stem volume (m^3), DBH is the diameter at breast height (cm), and H is the total tree height (m).

Table 1. *Pinus maximinoi*, *P. tecunumanii* families and *P. patula* planted at Turbo Forestry Research Station, Kenya

No.	***P. tecumumanii* families**	***P. maximinoi* families**
1	Patula	Patula
2	2343	862
3	125	906
4	2366	961
5	2367	865
6	9999	871
7	2355	905
8	1102	959
9	2370	958
10	2346	861
11	2345	868
12	2390	888
13	93	887
14	89	999
15	2365	886
16	2394	870
17	10	875
18	2323	863
19	2375	907
20	2344	
21	9999	
22	1103	

No.	*P. tecumumanii* families	*P. maximinoi* families
23	2360	
24	30	
25	2342	
26	26	
27	193	
28	2356	
29	2358	
30	25	
31	38	
32	2369	
33	83	
34	37	
35	2350	

Data analysis

The data for parameters assed were analyzed using a computer statistical package GenStat18th edition (Payne *et al*., 2015). Analyses of variance (ANOVA) at the 0.05 significance level and least significant difference (LSD) tests were calculated for height, DBH and tree volume using the GLM procedure.

Results and Discussions

Survival

There were variations in survival within families being tested. Most of families of *Pinus maximinoi* and *P. tecunumanii* showed good survival rate with mean of 89.2 and 78.3 %, respectively. These figures are matching that of the local *Pinus patula* where the mean survival rate was 79.1 % (Table 2 and 3).

Height, diameter at breast height (dbh) and volume

During the first four years, the variations among families were minimal especially in height increase. But in the fifth year significant variations showed among the families of *P. maximinoi* in height, dbh and juvenile tree volume. Family No.863 and 907 of *P. maximinoi* had the highest mean height of 10.7 and 10.1 m respectively. While family No. 961 of the same species had the lowest mean height of about 6.8 m (Table 2). Local *P. patula*, which acted as a control had a mean height of 8.3 m. Although there were no major significant differences ($P \leq 0.05$) in height growth, dbh and juvenile tree volume among the various families of *P. tecunumanii*, family No.2358 had the best mean height growth of 8.7 m while family No. 93 had the lowest mean height growth of 6.7 m (Table 3).

Diameter at breast height in *P. maximinoi* families indicated two families No. 863 and 907, which had the highest, mean height had the best dbh of 15.2 and 14.55 cm respectively and this also translated to the best volume of 0.0737 m^3 for family No. 863. The local *P. patula* had an average dbh of 11.14 cm and volume of 0.0285 m^3. Family No. 2342 of *P. tecunumanii* was the best performers in volume (0.0369 m^3).

Table 2. Comparison of the mean growth of 5 year old *Pinus maximinoi* and *P. patula* at Turbo (means were separated using Tukeys test)

Families	**%Survival**	**Height (m)**		**DBH(cm)**		**Volume (m^3)**	
961	75	6.8	a	8.81	a	0.0136	a
862	75	6.8	a	10.17	a	0.0164	a
906	93.8	8.1	ab	11.20	abcd	0.0330	abc
865	80	8.1	ab	10.70	a	0.0312	a
Patula	79.2	8.3	abc	11.14	abc	0.0285	a
958	95	8.5	abc	11.85	abcd	0.0365	abc
870	100	8.5	abc	13.88	abcd	0.0504	abcd
959	75	8.8	abc	11.81	abcd	0.0307	a
886	95	8.9	abc	12.48	abcd	0.0420	abcd
861	87.5	9.0	abc	13.30	abcd	0.0425	abcd
868	100	9.1	abc	11.76	abcd	0.0419	abcd
887	100	9.1	abc	11.01	ab	0.0339	abc
871	90	9.3	abc	12.18	abcd	0.0398	abc
905	100	9.5	abc	12.10	abcd	0.0423	abcd
875	95	9.7	bc	13.16	abcd	0.0499	abcd
999	95	9.8	bc	12.44	abcd	0.0443	abcd
888	100	10.0	abc	13.89	abcd	0.0598	abcd
907	50	10.1	abc	14.55	abcd	0.0324	ab
863	100	10.7	c	15.02	bd	0.0737	bd
Mean		8.8		12.02		0.0387	
LSD		1.82		2.84		0.0232	
SED		0.91		1.41		0.0196	
(P = 0.05)		<.001		0.002		<.001	

Table 3. Comparisons of the mean growth of 5 years *Pinus tecunumanii* and *P. patula* planted at Turbo, Kenya (means were separated using Tukeys test)

Families	%Survival	Height (m)		DBH(cm)		Volume (m3)	
93	58.3	6.7	a	9.28	a	0.0188	a
125	83.3	7.3	a	10.73	a	0.0208	a
2367	70.8	7.4	a	10.80	a	0.0240	a
26	66.7	7.4	a	10.38	a	0.0216	a
2394	75.0	7.4	a	10.43	a	0.0269	a
9999	83.3	7.5	a	10.52	a	0.0296	a
1102	62.5	7.5	a	10.93	a	0.0183	a
2365	95.8	7.5	a	11.38	a	0.0332	a
2345	75.0	7.5	a	10.20	a	0.0232	a
2366	65.0	7.7	a	10.48	a	0.0177	a
2346	70.8	7.7	a	10.94	a	0.0258	a
2375	70.0	7.7	a	11.43	a	0.0238	a
10	91.7	7.7	a	10.83	a	0.0279	a
2370	80.0	7.7	a	11.96	a	0.0280	a
37	90.0	7.7	a	10.98	a	0.0277	a
83	85.0	7.8	a	10.93	a	0.0302	a
2343	70.0	7.8	a	11.06	a	0.0239	a
Patula	79.1	7.8	a	10.13	a	0.0157	a
2369	79.2	7.8	a	11.79	a	0.0343	a
1103	75.0	7.9	a	11.59	a	0.0271	a
193	91.7	8.0	a	12.16	a	0.0345	a
89	87.5	8.0	a	11.01	a	0.0238	a
30	75.0	8.0	a	12.14	a	0.0302	a
2356	80.0	8.1	a	11.64	a	0.0304	a
25	80.0	8.1	a	11.99	a	0.0334	a
2323	75.0	8.1	a	11.81	a	0.0280	a
2350	83.3	8.2	a	11.58	a	0.0312	a
2360	75.0	8.3	a	11.77	a	0.0266	a
38	79.2	8.3	a	12.21	a	0.0326	a
2342	82.1	8.4	a	12.90	a	0.0369	a
2355	87.5	8.5	a	12.33	a	0.0354	a
2344	87.5	8.5	a	12.45	a	0.0366	a
2358	75.0	8.7	a	11.48	a	0.0318	a
Mean		7.816		1.135		0.0276	
LSD		1.135		2.194		0.0152	
(*P* = 0.05)		0.42		0.346		0.298	

After two years of establishment, *P. maximinoi* had a faster growth rate than *P. tecunumanii* (Figure1). When dbh and volume were assessed from year 3 to year 5, *P. maximinoi* showed better growth than *P. tecunumanii* (Figure 2 and 3). These observations are based on experimental conditions at Turbo and may not reflect the situation in other parts of the country where pines are planted.

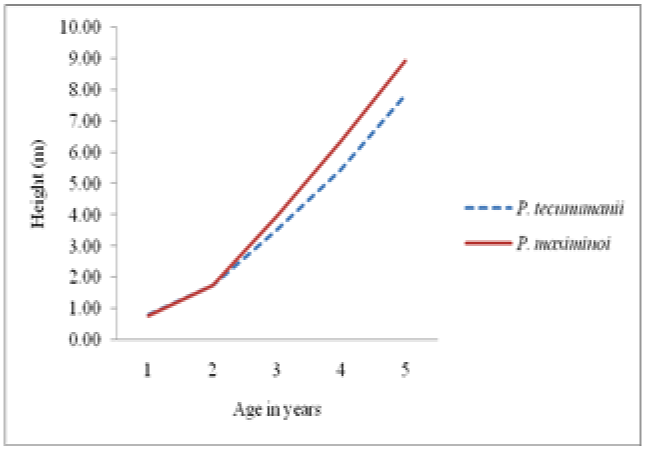

Figure 1. Growth pattern of the *P. maximinoi* and *P. tecunumanii* over 5 years

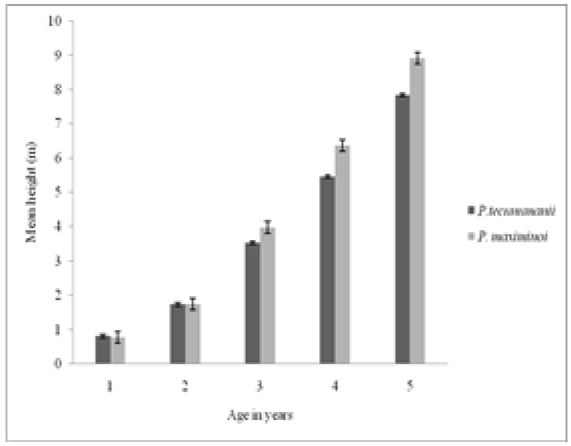

Figure 2. Annual mean height of the of *P. maximinoi* and *P. tecunumanii* over 5 years of establishment

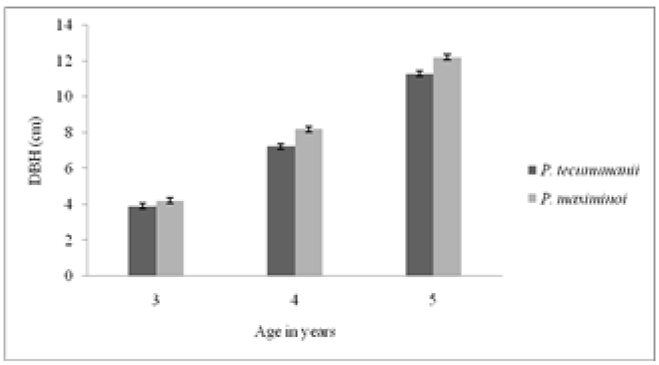

Figure 3. Mean diameter at breast height (DBH) growth of *P. maximinoi* and *P. tecunumanii* over a period of 5 years

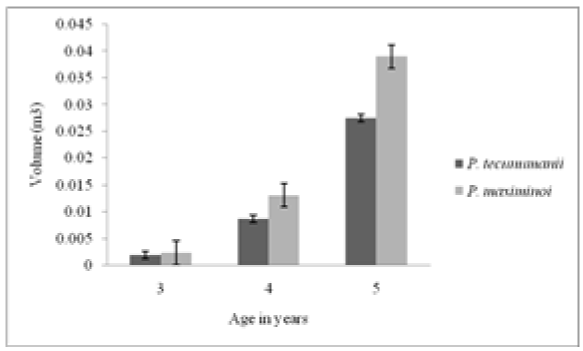

Figure 4. Mean volume accumulation of *P. maximinoi* and *P. tecunumanii* over a period of 5 years

Discussion

The growth performances of both the progenies of *Pinus maximinoi* and *P. tecunumanii* compared to the local *Pinus patula* is remarkable and their introductions will increase the variety of soft wood species within the Kenyan forest plantation. Since the two sets of the progeny trials were set adjacent to one another, it show that *P. maximinoi* at early stages grows faster than *P. tecunumanii* in the prevailing weather conditions of Turbo area. Further monitoring will reveal the growth behaviors of the potential species and if possible considered for expansion. The progeny tests described in this paper considered the number of tested candidates, number of replicates (progenies) per candidate as is usually recommended (Hannrup *et al.*, 2007). Putting the above factors into consideration ensures sustainable genetic diversity in long-term breeding based on balanced within family selection. Selection within-family maintains an equal representation among parents and is an efficient strategy for forest trees (Rosvall *et al.*, 2003). With this strategy, genetic variance and genetic diversity are preserved in the breeding populations.

So far the progenies of *P. tecunumanii* have not shown major variations in their growth pattern in Turbo area so the choice of the families to be adopted is still wide. Meanwhile the variations being observed in *P. maximinoi* progenies will guide in the selection of the suitable families for expanded planting in Kenya.

Conclusions and Recommendations

The results showed significant differences among families, indicating that the value of selection among families for both species was high. Due to the better performance of some of the families of both *P. maximinoi* and *P. tecunumanii*, compared to the popularly grown *P. patula*. It is recommended that *Pinus maximinoi* and *P. tecunumanii* be established in pilot plantations and more introductions of the best performing families be introduced for large scale planting. This will diversify pine tree species planted for softwood or pulp production as opposed to the current reliance on *Pinus patula* as commercial soft wood plantation in highlands of Kenya.

Acknowledgement

We sincerely acknowledge the technical support provided by the CAMCORE team and the supply of test materials. Further appreciation goes to the field data collection team at KEFRI Turbo Sub-Centre led by the forester Mr. Lawrence Simiyu and Shadrack Abila, and for establishment and maintenance of the trials. KEFRI management provided the enabling environment to undertake the trial.

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Genotypic and Plant Growth Regulator Interaction on Propagation of Jojoba (*Simmondsia chinensis L.*) Cuttings in Semi-arid Areas of Voi, Kenya

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Abstract
Asexual propagation is necessary to provide known sex plants in jojoba to boost yields. An experiment was set up to identify the most appropriate Plant Growth Regulator (PGR) and genotype interaction for propagation of cuttings in semi- arid areas of Kenya. The experiment was a 4^2 factorial laid down in a RCBD with 16 treatments replicated 3 times. The treatments consisted of 2 factors namely: PGR and genotype and 4 levels of PGRs which were IBA, Roothom, Anatone and the Control while those of genotypes were M1= male 1, M2= male 2, F1= female 1 and F2= female 2. ANOVA was carried out using SAS package whereas the significantly different treatment means were separated using DMRT at $p \leq 0.05$. The trial was carried out for 5 months in 2013 at Wildlife works Ltd, Voi. Results showed that Anatone x M2 interaction was the best for rooting (62.7 %) whereas IBA x M1 interaction showed the highest performance in most of the variables measured for shoot and foliage growth. This study recommends the use of Anatone x M2 genotype interaction for future propagation of jojoba cuttings. However, further research is recommended on screening of a wide range of PGR x genotype for propagation of jojoba cuttings in semi-arid areas of Kenya.

Keywords: Genotype, Plant Growth Regulator, jojoba, cuttings

Introduction
Jojoba is a high value shrub and a promising cash crop for arid and semi arid lands (ASALs) (Ahmad, 2001; Reddy and Chikara, 2010). The plant produces nuts with 50 % of its weight as oil which is similar to that obtained from sperm whale (Hogan and Bemis, 1983). The oil is important in cosmetics, lubricant industry, pharmaceuticals and electronics (Undersander *et al*., 1990; Ward, 2003).

The success of jojoba cultivation depends upon selection of high-yielding genotypes and their multiplication through vegetative means (Al-Obaidi *et al*., 2017). Propagating jojoba by direct seeding has genetic heterogeneity, which has raised doubts about the economic feasibility of cultivating jojoba (Kumar *et al*., 2012). For vegetatively propagated plants, the ability to root is affected by the genotype (Bashir *et al*. 2008; Inoti *et al*., 2016), cultural factors (Foster *et al*.,

1984) and maturation (Ozel *et al*., 2006). A lot of work on vegetative propagation in semi-hardwoods has been done especially in temperate environments but a lot more is needed in tropical areas in order to determine the optimum requirement for jojoba cuttings in the latter region (Bashir *et al*., 2001, 2013). The advantages of using asexual propagules in commercial jojoba plantations are that they provide uniform and predictable plant growth and yield (Lee, 1988; Chaturvedi and Sharma, 1989) and can be sexed earlier before flowering.

There is a wide range of Plant Growth Regulators (PGRs) in the market and are available for use by commercial nurseries and in horticultural farms. However, they vary greatly in their performance when combined with various genotypes (Inoti *et al*, 2016). It is, therefore, of necessity to test different PGRs such as Anatone, Rothoom and others together with specific genotype combination in order to recommend the best for root initiation in jojoba cuttings. This will provide a cheaper and more accessible method for vegetative propagation of jojoba for scaling up elite plantations.

Rooting hormones in plants stimulate the formation of new root tips in stem cuttings. Two synthetic auxins namely Indole butyric acid (IBA) and α-naphthalene acetic acid (NAA) are mostly used, either singly or in a combination. Rooting hormones or PGRs wholly cause a greater percentage of cuttings to root, hasten the formation of roots, induce more roots of cuttings and increase root uniformity (Godfrey *et al*., 1996; Inoti *et al*., 2016). These are used in different concentrations and Bashir *et al*. (2009) recommended up to 10 000 mgL^{-1} for jojoba. High concentrations of auxins promoted cell division which increased the number of roots (Palzkill, 1988).

Bashir *et al*. (2008, 2009) reported effect of jojoba strain x auxin interaction to be significant for all the root parameters. Similarly, Bashir *et al*. (2007) reported significant effect by interactions of jojoba strains and growth regulator combinations on number of shoots and primary root length *in vitro*. Other studies by Owais (2010) reported that rootability of pomegranate is influenced by the interactive effect of cutting age, IBA concentration and variety whereas studies by Rogalski *et al*. (2003) reported significant interaction effects between genotype and IBA concentration in Prunus rootstocks for survival.

Bashir *et al*. (2009) reported two-way interaction between jojoba strains and auxins which was significant for all the root parameters as well as for number of leaves per cutting and length and diameter of primary shoot. PKJ-3 strain performed the best compared with PKJ-2 strain which was the least. Interaction between auxin and their concentration significantly affected all the root parameters except the length of the primary root.

Currently, there is low production of jojoba despite high demand mainly due to high ratio of male to female bushes in the existing plantations since most of them were raised from seed.

There is need to vegetatively propagate jojoba through selection of superior genotypes. An experiment was set up with the aim of identifying the most appropriate PGR and genotype interaction for propagation of jojoba cuttings in semi-arid areas of Kenya.

Materials and Methods

Site description

The research was conducted at Rukinga Wildlife Works Ltd, Maungu, Voi, where jojoba bushes have been established. It is located 20 km east of Voi urban centre, Voi District, Taita Taveta County, Coast region of Kenya. The study site lies in the semi-arid savannah which receives an average annual rainfall of 458 mm with a bimodal pattern of distribution. Long rains are received between March and May while the short rains are received between November and December Temperatures range from 16-37^{0}C with an average of 25^{0}C with moderate relative humidity of 59 % and annual number of rainy days being 42.7 (TTDP 2008). Soils are moderately fertile with sandy loam and gravel texture and pH of 5-7 (Thagana *et al*., 2003).

Experimental design and sampling techniques

The experiment was a 4^2 factorial laid down in a Randomized Complete Block Design (Gomez and Gomez, 1984) with 16 treatments replicated 3 times (Table 1). The treatments consisted of 2 factors namely: PGR and genotype at 4 levels each. PGR levels were IBA, Roothom, Anatone and Control while genotypes were male 1, male 2, female 1 and female 2.

A total of 40 stem cuttings were randomly harvested from each genotype and their combination with the PGRs constituted a replicate. The treatment combinations per replicate were as follows: M1I, M1R, M1A, M1C, M2I, M2R, M2A, M2C, F1I, F1R, F1A, F1C, F2I, F2R, F2A, F2C where M1- male 1 genotype, M2- male 2 genotype, F1- female 1 genotype, F2- female 2 genotype. On the other hand, I, R, A, C refer to: IBA, Rothoom, Anatone and Control respectively. The treatment combinations were independently and randomly allocated to each replicate. Each treatment consisted of 10 potted plants. This trial was carried out from April to August 2013.

The stem cuttings were harvested at the dormant stage and each twig consisted of 5 nodes. IBA was applied at a rate of 5000 mgL^{-1} + 15.5 boric acid and this was put in containers where the freshly cut twigs were quickly dipped for 10 seconds before planting in a sterilized sand container. Roothom (with 0.6 % IBA) was applied in powder form which involved dipping the basal freshly cut portion into the powder followed by planting.

Table 1. Experimental layout on the effect of PGR x genotype on macro-propagation of jojoba cuttings

REP 1	REP 2	REP 3
M21	F1A	F1R
M1A	M2A	F2R
F1R	F1C	M2R
F2C	M2R	M1A
F2I	M21	F1A
M1I	F2I	F1R
F1A	M2C	F1C
M2C	M1C	M2C
F1I	F1R	F2A
M2A	M1R	M21
F1C	F1R	F1I
M1R	F2R	M1C
F2A	M1A	M1I
F2R	F1I	F2I
M1C	F2A	M2A
M2R	M1I	M1R

Key: Genotypes consist of male (M1and M2) and female (FI and F2) whereas plant growth regulators consist of IBA, Roothom, Anatone and Control represented by I, R, A and C, respectively. Treatments consist of combinations of both genotype and PGR.

On the other hand, Anatone was applied at a rate of 1000 mgL^{-1} of water according to manufacturers' recommendations. This was placed in a container where the freshly cut twigs were dipped for a period of 5 minutes and then planted in a polythene sheet tunnel. The cuttings were left to grow for five months (Plate 1).

Three rooted cuttings were randomly sampled per treatment. The variables scored from rooted cuttings were: survival percent, rooting percent, plant height, height of new growth, number of shoots, internode length, leaf length, leaf width, number of leaves, single leaf area, total leaf area, root collar diameter, number of roots, root length, fresh shoot biomass and fresh total plant biomass.

Plate 1. Sprouting jojoba cuttings inside a polythene sheet tunnel

Data analysis

A two-way Analysis of Variance (ANOVA) was carried out using SAS statistical package (SAS 1996) whereas the means were separated using Duncan's multiple range test (DMRT) at $p \leq 0.05$.

Results

Effect of PGR × genotype interaction on survival and rooting of jojoba cuttings

Results showed significant interaction ($p < 0.05$) between PGRs and genotypes in all the variables measured which included survival percent, rooting percent and root growth (Table 2). The highest survival percentage was shown by Roothom × F2 interaction (93.3 %) while the lowest was Roothom × M2 interaction (29.3 %). The former was significantly greater ($p < 0.01$) than IBA × F1, IBA × M2, Roothom × F1, Roothom × M2, Anatone × M1, Control × F1, Control × M1 and Control × M2. On the other hand, F2 interactions gave outstanding superior performance in survival percent (87.7-93.3 %) compared with the overall mean of 64.9 % whereas F1 genotype × PGR interactions showed the lowest rooting percent (0-4.3 %) compared with the overall mean of 17.9 %.

Table 2. Effect of interaction between PGRs and genotypes on the survival and rooting percentages and root growth of jojoba cuttings

PGR × G Interaction	**Survival %**	**Rooting %**	**Root length (cm)**	**Number of roots**	**Root collar diameter (mm)**
IBA × F1	46.0cd	0.0f	-	-	-
IBA × F2	91.7a	8.7def	19.2abc	27.3abcd	2.0ab
IBA × M1	63.0abc	37.7b	30.0a	43.0a	3.0a
IBA × M2	50.0cd	37.7b	30.3a	28.9abcd	3.2a
Roothom × F1	58.7bcd	0.0f	-	-	-
Roothom × F2	93.3a	13.0cdef	22.3ab	29.7abc	3.7a
Roothom × M1	66.7abc	25.3bcd	12.7abc	21.8abcd	2.2ab
Roothom × M2	29.3d	21.0bcde	29.8a	39.5ab	3.3a
Anatone × F1	71.0abc	4.3ef	12.9abc	5.0cd	1.3ab
Anatone × F2	92.0a	8.7def	7.2bc	9.7cd	1.0ab
Anatone × M1	50.0cd	21.0bcde	16.8abc	28.5abcd	2.7ab
Anatone × M2	67.0abc	62.7a	28.3ab	29.7abc	2.8a
Control × F1	54.7cd	4.3ef	7.7bc	7.7cd	1.3ab
Control × F2	87.7ab	0.0f	-	-	-
Control × M1	58.7bcd	0.7cdef	9.0abc	12.0bcd	1.8ab
Control × M2	58.3bcd	29.0bc	22.4ab	27.7abcd	3.0a
CV	26	56.6	72.8	77	2.2
Std Dev	24.3	18.9	14.2	18.7	1.7
P value	0.0014	<.0001	0.0073	0.0083	0.0251

Means with the same letter(s) in each column are not significantly different to each other according to DMRT at p < 0.05. G= genotype

Rooting percentage was highest for Anatone × M2 interaction (62.7 %) which was significantly higher (p < 0001) to all the PGR × genotype interactions considered. Rooting did not occur in IBA × FI, Roothom × F1 and also Control × F2, hence excluded from the other growth variables. IBA × M2 interaction showed the highest root length (30.3 cm) which was significantly higher (p < 0.01) than IBA × M1, Anatone × F2 and Control × F1 interactions. Similarly, IBA × M1 interaction showed the highest number of roots (43) which were significantly superior (p < 0.01) to Anatone × F1, Anatone × F2, Control × F1 and Control × M1 interactions. On the other hand, Roothom × F2 interaction showed the highest root collar diameter (3.7 mm) though not significant compared with the other interactions while Anatone × F2 interaction showed the lowest (1.0 mm).

All the PGR × genotype interactions were comparable in performance for survival percent, rooting percent and root growth. However, F2 interactions gave outstanding superior performance in survival percent compared with the other interactions. For root length, IBA × M2 interaction gave the best results, while Anatone × M2 interaction also showed the best rooting percent. For number of roots and root collar diameter, IBA × M1 and Roothom x F2 interactions gave the highest values, respectively.

Effect of PGRS × genotype interactions on the shoot growth of jojoba cuttings

Significant interaction ($p \leq 0.01$) was showed by PGRs × genotypes for shoot and foliage growth (Table 2) with the exception of IBA × FI, Roothom × F1 and Control × F2 since they did not root. For all the shoot and foliage variables measured, IBA × M1 interaction showed the highest growth in leaf length, number of leaves, total leaf area, height of new growth and total plant biomass.

Leaf length for IBA × M1 interaction was significantly higher ($p < 0.01$) than Anatone × F1, Anatone × F2, Control × F1 and Control × M1 interactions. IBA × M1 interaction showed significantly higher number of leaves (21.3) relative to all the other PGR × genotype interactions. IBA × M1 interaction showed significantly greater ($p < 0.01$) total leaf area (78.5 cm^2) compared with all the other PGR × genotype interactions except the Control × M2 interaction (49.9 cm^2) which was not significant. IBA × M1 interaction showed significantly higher height of new growth in cuttings (13.2 cm) compared with all the other PGR × genotype interactions except the Anatone × M2 interaction (8.3 cm) which was not significant. IBA × M1 interaction showed significantly higher ($p < 0.01$) total plant biomass (3.7 g) compared with IBA × F2, Anatone × F1, Anatone × F2, Control × F1 and Control × M1 interactions.

For leaf width, the Control × M2 interaction gave the highest width (18 mm) which was significantly larger than IBA × F2, Anatone × F1, Anatone × F2, Control × F1 and Control × M1 interactions. Single leaf area was highest for Anatone × M2 interaction (5.2 cm^2) and was significantly higher ($p <.0001$) than all the other PGR × genotype interactions except IBA × M1, IBA × M2, Roothom × M1, Roothom × M2 and Control × M2 interactions.

Height was highest for Roothom × F2 interaction (17.6 cm) which was significantly superior ($p \leq 0.01$) compared with Anatone × F1, Anatone × F2 and Control × F1 interactions. Similarly, internode length was highest for Anatone × M2 interaction (27.8 mm) which was significantly higher than Anatone × F2 interaction (6 mm).

Table 2. Effect of PGRs and genotype interactions on the shoot growth of jojoba cuttings

PGR×G Interaction	Height (cm)	Height of new growth (cm)	Internode length (mm)	Total fresh plant biomass (g)
IBA × F1	-	-	-	-
IBA × F2	7.4abc	3.5bcd	13.0abc	0.7bc
IBA × M1	16.3ab	13.2a	27.7a	3.7a
IBA × M2	11.3abc	7.1bc	22.9ab	2.6ab
Roothom × F1	-	-	-	-
Roothom × F2	17.6a	5.4bcd	22.3ab	3.3a
Roothom× M1	8.1abc	6.1bcd	17.3abc	1.5abc
Roothom× M2	13.6ab	6.9bc	27.3a	2.3ab
Anatone × F1	4.7bc	3.0bcd	8.0abc	1.0bc
Anatone × F2	4.7bc	1.1cd	6.0bc	0.7bc
Anatone × M1	14.6ab	6.6bc	16.8abc	2.0abc
Anatone × M2	12.3ab	8.3ab	27.8a	2.7ab
Control × F1	5.3bc	1.7cd	8.7abc	1.0bc
Control × F2	-	-	-	-
Control × M1	7.3abc	4.5bcd	12.8abc	0.7bc
Control × M2	11.4abc	6.7bc	9.2abc	2.7ab
CV	72.6	67.8	71.8	75.3
Std Dev	77.5	4.4	12.8	1.5
P value	0.0108	0.0006	0.0028	0.0028

Means with the same letter(s) in each column are not significantly different to each other according to DMRT at $p \leq 0.01$. G= genotype

IBA × M1 interaction showed the highest performance in most of the variables measured for shoot and foliage growth. Male genotypes especially M1 showed the best performance in shoot and foliage growth compared with the female genotypes. This was clearly demonstrated in total fresh plant biomass, leaf width, single leaf area and internode length. IBA also showed the highest performance compared with the other PGRs in the shoot and foliage growth.

Effect of PGRS × genotype interactions on the foliage growth of jojoba cuttings

Significant interaction ($p \leq 0.01$) was showed by PGRs × genotypes foliage growth (Table 3) with the exception of IBA × FI, Roothom × F1 and Control × F2 since they did not root. For all the foliage variables measured, IBA × M1 interaction showed the highest growth in leaf length, number of leaves and total leaf area.

Leaf length for IBA × M1 interaction was significantly higher ($p < 0.01$) than Anatone × F1, Anatone × F2, Control × F1 and Control × M1 interactions. IBA × M1 interaction showed significantly higher number of leaves (21.3) relative to all the other PGR × genotype interactions. IBA × M1 interaction showed significantly greater ($p < 0.01$) total leaf area (78.5 cm^2) compared with all the other PGR × genotype interactions except the Control × M2 interaction (49.9 cm^2) which was not significant.

For leaf width, the Control × M2 interaction gave the highest width (18 mm) which was significantly larger than IBA × F2, Anatone × F1, Anatone × F2, Control × F1 and Control × M1 interactions. Single leaf area was highest for Anatone × M2 interaction (5.2 cm^2) and was significantly higher ($p <.0001$) than all the other PGR × genotype interactions except IBA × M1, IBA × M2, Roothom × M1, Roothom × M2 and Control × M2 interactions.

Table 3. Effect of PGRs and genotype interactions on the foliage growth of jojoba cuttings

PGR×G Interaction	Leaf length (mm)	Leaf width (mm)	Number of leaves	Single leaf area (cm^2)	Total leaf area (cm^2)
IBA × F1	-	-	-	-	-
IBA × F2	20.7abcd	7.0bcd	3.7bc	1.2cdef	3.5def
IBA × M1	42.5a	15.5abc	21.3a	3.8ab	78.5a
IBA × M2	28.7abc	14.6abc	9.6bc	3.6abc	33.2bcdef
Roothom × F1	-	-	-	-	-
Roothom × F2	23.7abcd	10.3abcd	9.7bc	2.0cdef	20.1bcdef
Roothom× M1	25.3abc	10.2abcd	7.3bc	3.1abcd	33.8bcdef
Roothom× M2	37.3ab	16.3ab	9.8bc	4.2ab	41.4bc
Anatone × F1	11.3cd	5.7cd	3.3bc	1.3cdef	12.7cdef
Anatone × F2	5.0cd	2.0d	2.7bc	0.3ef	2.7ef
Anatone × M1	28.3abc	9.5abcd	10.0bc	2.6bcde	37.0bcde
Anatone × M2	40.7a	17.9a	7.4bc	5.2a	38.7bcd
Control × F1	8.7cd	2.3d	3.0bc	0.7def	6.3cdef
Control × F2	-	-	-	-	-
Control × M1	13.3bcd	6.7bcd	6.0bc	1.1cdef	9.6cdef
Control × M2	39.8a	18.0a	11.3b	4.2ab	49.9ab
CV	62.4	63.1	79.6	63.7	80
Std Dev	18.1	7.7	6.9	2	26.9
P value	0.0003	0.0002	0.0023	<.0001	0.0002

Means with the same letter(s) in each column are not significantly different to each other according to DMRT at $p \leq 0.01$. G= genotype

IBA × M1 interaction showed the highest performance in most of the variables measured for foliage growth. Male genotypes especially M1 showed the best performance in foliage growth compared with the female genotypes. This was clearly demonstrated in leaf width and single leaf area. IBA also showed the highest performance compared with the other PGRs in the foliage growth.

Discussion

Anatone × M2 interaction was the best for rooting (62.7 %) and was significantly higher relative to all the interactions. All the PGR × genotype interactions showed significant differences relative to the control in all the variables measured with the exception of root collar diameter and internode length. However, there are limited studies on auxin × genotype interactions in jojoba and other semi-hardwoods in the tropics.

This study is consistent with the work by Bashir *et al*. (2008) who reported effect of jojoba strain × auxin interaction to be significant for all the root parameters as well as for number of leaves, length and diameter of primary shoot. Strain × auxin concentration was also significantly different for diameter of primary root, number of leaves and shoot length. Similarly, Bashir *et al*. (2007) reported significant effect by interactions of jojoba strains and growth regulator combinations on number of shoots and primary root length *in vitro*.

Other studies by Owais (2010) reported that rootability of pomegranate is influenced by the interactive effect of cutting age, IBA concentration and variety. Significant interaction effect was observed in rooting percent, number of roots and weight of roots. Further work by Ansari (2013) and Sarrou *et al*. (2014) reported significant interaction effect between time of cutting collection, media, auxin and cutting thickness on rooting characteristics in pomegranate. Sarrou *et al*. (2014) observed that melatonin can be substituted for IBA to produce rooting. Studies by Rogalski *et al*. (2003) reported significant interaction effects between genotype and IBA concentration in Prunus rootstocks for survival which corroborates with the present study. Khattab *et al*. (2014) showed significant effect on rooting due to interaction between auxin, cutting date and wounding in jojoba cuttings which was consistent with a study reported by Hegazi *et al*. (2010) on olive cultivars. Further research by Bashir *et al*. (2013) reported significant differences between jojoba genotypes when combined with IBA which is in agreement with this study.

Hasanuzzaman *et al*. (2007) noted significant effect between genotypes and synthetic hormones (Milstim and litosen) interaction in *Capsicum annum* for number of leaves which is consistent with the findings of this study. However, they found that height and number of branches were not significant which was contradictory to the current findings. Similarly, work by Kesari *et al*. (2010) contradicted this study by stating that interaction among auxins, genotypes and month of collection had no significant effect on root induction and differentiation in *Pongamia pinnata*. Some bacteria such as those belonging to the genus *Agrobacterium* and rhizobia release auxin and can have positive effect on rooting of cuttings (Sezai *et al*., 2003). Dodd *et al*. (2010) reported interaction between bacteria isolates and apple rootstock genotype which resulted in elongation of roots. Similar results were reported by Gosal *et al*. (2010).

Conclusion

Anatone × M2 interaction was the best for rooting (62.7 %) and was significantly higher relative to all the interactions. Similarly, all the PGRs (IBA, Anatone and Roothom) × genotype interaction showed superior performance relative to the control in all the variables measured with the exception of root collar diameter and internode length.

Recommendations

Propagation of jojoba cuttings using Anatone × M2 interaction is recommended by this study. However, there are more prospects for further interaction studies between various PGRs and female genotypes in order to get the best combination for scaling up production in ASALs.

Acknowledgement

The author wish to sincerely thank Wildlife Works Ltd for their financial support in conducting this research.

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Seed Borne Mycoflora Associated with Stored Seeds of Three Tree Species at The Kenya Forestry Seed Centre

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Abstract

Seed are a main source of planting material and medium of germplasm exchange. However, Seed-borne pathogens of trees reduce seed germination rate and longevity in storage; cause deformation and decay of seeds; and affect seedling vigour. Limited research has been conducted in Kenya on prevention and control of seed borne diseases of forest tree species compared to agricultural crops. This study was undertaken to identify and determine seed borne fungi associated with seed lots of provenances of *Grevillea robusta, Moringa oleifera* and *Dalbergia melanoxylon* stored at the Kenya Forestry Seed Centre. Three methods of assaying seed borne fungi were used: agar plate, filter paper and blotter sheet. 400 seeds of each of the provenances were surface sterilized and another set of non-surface sterilized were sown on blotter in four replicates. Two hundred seeds were surface sterilized and another set of non-surface sterilized were sown on filter paper in 20 replicates. Four hundred seeds of each species were surface sterilized and another set of non-surface sterilized were plated on malt extract agar in 40 petri dishes. Seed health testing using the agar plate method detected a large number of storage and field fungi that included: *Phoma sp, Nectria sp, Fusarium sp, Cladosporium sp., Pestalotia sp., Botryosphaeria sp., Aspergillus sp., Rhizoctonia sp., Monilia sp., Altenaria sp*.and *Mycelia sterilia*. *The seed of Dalbergia melanoxylon* was heavily infested (96%) with *Fusarium sp*. Many of the isolated field fungi are potential pathogens of seed and seedlings of the species they were isolated from especially during storage and in the nursery. These observations indicate that seed of the three tree species obtained from the Kenya Forestry Seed Centre harbored a range of seed borne fungi. Further studies need to be undertaken on other tree species prone to fungal attack during germination tests.

Keywords: Seed borne, pathogens, mycoflora, seeds, tree species, Kenya Forestry Seed Centre.

Introduction

Seeds are regarded as a highly effective means for transporting plant pathogens over long distances. However, when compared to seed-borne disease problems of agricultural crops, limited research has been undertaken on forest tree species and in the development of disease prevention and control practices. Various fungal species are commonly associated with seeds of many tree species including both pathogens and saprophytes. Several species of fungi which are generally considered as saprophytes behave as pathogens under conducive moisture and temperature causing injury to the seed or seed coat. These conditions favour growth and increase the physiological and vulnerability of tree cones and fruits, seeds, and subsequently seedlings to infection (Mittal *et al.*, 1990). Seed-borne pathogens of trees reduce seed germination rate and longevity in storage; cause deformation and decay of seeds; and affect seedling vigour (Sutherland *et al.*, 2002). It is important to undertake seed health testing since existence of pathogens on seeds may transfer diseases to ensuing crops. Seed health of *Moringa oleifera*, *Dalbergia melanoxylon* and *Grevillea robusta* were undertaken to determine the existence of pathogenic fungi on the seedlots. *Grevillea robusta* which is native to Eastern Australia is widely planted in high and medium potential zones. It is common on farms in the Central Highlands of Kenya, and used for timber, poles, posts and fuelwood. It is also used as bee forage, fodder, mulch,as well as for soil conservation and windbreak. *Grevillea robusta* has been reported to be infected with *Botrysphaera* stem canker (Njuguna *et al.*, 2011).

Moringa oleifera has been naturalized and widely planted in Semi-arid areas and at the Kenyan Coast. The species has several uses that include food, fodder, edible oil from seeds, water purification, and medicine. Preliminary studies on seed and soil borne pathogenic fungi of this species have been undertaken by Riad *et al.* (2014).

Dalbergia melanoxylon is an endangered indigenous species occurring in dry deciduous woodlands, coastal bushland and wooded grassland. Its wood is very hard, durable, termite resistant and of high value. It is also used as medicine,, fodder, mulch and green manure (Omondi *et al.*, 2002). Little is known of its pathogens.

In many parts of the world, testing tree germplasm for seed borne diseases is an integral part of routine inspection for seed quality. Seed health testing at the KEFRI seed centre is not undertaken as part of routine seed laboratory tests. This study was undertaken on the three tree species: *G. robusta, M. oleifera* and *Dalbergia melanoxylon* to determine presence of seed borne pathogens.

Materials and Methods

Seeds were sampled from two seedlots each of *Grevillea robusta* (Laikipia and Loitoktok), *Moringa oleifera* (Ramisi and Ramogi), and *Dalbergia melanoxylon* (Kibwezi and Ikanga) at KEFRI Seed Centre. Seed surface fungi were assessed on the three species by the standard blotter technique (ISTA 1985). Four hundred seeds of each of the two provenances were surface sterilized (SS) with 5% sodium hypochlorite solution for 10 minutes, rinsed four times with distilled water. A second set of 400 non surface sterilized (NSS) control seeds were sown on blotter sheets in germination boxes in 4 replicates of 100 seeds each.

Two hundred seeds of each seedlot were surface sterilized (SS) as above. A second set of 200 non surface sterilized (NSS) control seeds were sown on filter paper on petri dishes in 20 replicates of 10 seeds each. The seeds were incubated for 10 days at 25°C in seed germinator and thereafter assessed and the number of infected seed and types of emerging fungi recorded.

Agar plate method (ISTA 1993) was used to detect seed borne fungi. Malt extract agar (MEA) medium was used for assessing seed borne fungi by the Agar plate method. Four hundred seeds of each seedlot were surface sterilized with 5% sodium hypochlorite solution for ten minutes, washed with sterile distilled water, blotted dry and plated on MEA medium. Four seeds were plated on MEA medium on each of the 100 plates and incubated for 8 days. Fungal colonies developing from the seeds were isolated, purified and identified. Identification of the seed-borne fungi was undertaken up to the generic level or species level in certain cases and the percentage occurrence of the fungi deduced.

Results

Moringa oleifera

A range of fungi comprising 9 fungal genera together with sterile mycelium were detected on seeds of two seedlots of *Moringa oleifera* (Table 1).

Table 1. Percent fungal occurrence on Surface Sterilized (SS) and Non surface sterilized (NSS) seeds of *M. oleifera* from 2 seedlots on different media

Seedlot	***Moringa oleifera Ramisi***					***Moringa oleifera Ramogi***				
Media	**Blotter sheet**		**Filter**		**Agar**	**Blotter sheet**		**Filter**		**Agar**
Fungi genera	SS	NSS	SS	NSS		SS	NSS	SS	NSS	
Fusarium	0.5	4.25	7	5.5	11.2	2.25	-	3.5	-	12.2
Botryosphaeria	-	-	-	-	7.46	-	-	-	-	-
Alternaria	-	-	-	-	2.49	-	-	-	-	3.65
Aspergillus	12	63.25	9.5	68	5.97	32.25	72.5	23.5	89	3.48
Rhizopus	7	32.5	12.5	26.5	5.7	17.25	27.5	20.5	11	5.72
Phoma	-	-	-	-	6.97	-	-	-	-	3.99
Cladosporium	-	-	-	-	-	-	-	-	-	1.24
Penicillium	-	-	0.5	-	-	0.25	-	-	-	2.73
Sterilemycelium	-	-	-	-	3.48	-	-	-	-	-
Nigrospora	-	-	-	-	2.74	-	-	-	-	-
Total	**19.5**	**100**	**29.5**	**100**	**46**	**52**	**100**	**47.5**	**100**	**34.9**

Among the two seedlots, the Ramisi seeddlot harboured more fungi than the Ramogi seedlot. Among the storage fungi, *Asperpegillus* sp and *Penicillium* sp were the dominant ones. The incidence of these fungi was dominant on blotter and filter paper incubation compared to Agar plate method. The occurrence of field fungi like *Fusarium* sp, *Botrosphaeria* sp, *Alternaria* sp, *Cladosporium* sp and *Phoma* sp were mainly isolated by the Agar plate method. The seedlot from Ramogi recorded a lower percentage of field fungi on Agar plate method compared to those from Ramisi. As expected the fungal genera, their frequency of occurrence as well as percentage of infestation were more on non-surface sterilized seeds from both seedlots.

Grevillea robusta

A range of fungi comprising 12 fungal genera were detected on seeds of two seedlots of *Grevillea robusta* (Table 2).

Table 2. Percentage fungal occurrence on Surface Sterilized (SS) and Non surface sterilized (NSS) seeds of *G. robusta* from 2 provenances on different media

Tree species	***Grevillea robusta (Loitokitok)***					***Grevillea robusta (Laikipia)***				
Media	**Blotter sheet**		**Filter**		**Agar**	**Blotter sheet**		**Filter**		**Agar**
Fungi genera	**SS**	**NSS**	**SS**	**NSS**		**SS**	**NSS**	**SS**	**NSS**	
Fusarium	-	-	-	-	0.25	-	-	-	-	-
Botryosphaeria	-	-	-	-	-	-	-	-	-	0.25
Alternaria	-	-	-	-	-	-	-	-	-	1
Aspergillus	43	93.25	37.5	100	6.5	0.25	72.75	85.5	100	-
Rhizopus	9.3	5.75	-	-	-	20.3	27.5	-	14	-
Phoma	-	-	-	-	2.25	-	-	-	-	10
Cladosporium	-	-	-	-	1.75	-	-	-	-	1.75
Penicillium	0.5	-	1.5	-	4.5	-	-	2	12	8.5
Rot fungus	-	-	-	-	0.5	-	-	-	-	0.25
Monilia	-	-	-	-	0.25	-	-	-	-	0.5
Nectria	-	-	-	-	-	-	-	-	-	0.5
Rhizoctonia	-	-	-	-	-	-	-	-	-	0.25
Pestalotia	-	-	-	-	-	-	-	-	-	0.25
Total	**53**	**99**	**39**	**100**	**16.3**	**20.5**	**100.25**	**87.5**	**126**	**23.3**

Among the two seedlots, the Laikipia seedlot harboured more fungi than the Loitoktok provenance. Among the storage moulds, *Aspergillus sp*, *Rhizopus sp* and *Penicillium sp* were the predominant fungi on blotter and filter paper test. Among the field recorded on seed of the two provenances on Agar medium, *Phoma sp* was dominant (10%) Other field fungi including *Pestalotia sp*, *Rhizoctonia sp*, *Nectria sp*, *Monilia sp*, *Botryosphaeria sp,* and *Fusarium sp* were less dominant (1%) on the Agar plate method. The provenance from Loitoktok recorded lower incidence of field fungi in the Agar plate method compared to the Laikipia one.

Dalbergia melanoxylon

Seven genera of fungi were detected on seed of the two provenances of *D. melanoxylon* (Table 3)

Table 3. Percent fungal occurrence on Surface Sterilized (SS) and Non surface sterilized (NSS) seeds of *D. melanoxylon* from 2 seedlots on different media

Tree species	***Dalbergia melanoxylon (Kibwezi***					***Dalbergia melanoxylon (Ikanga)***				
Media	**Blotter sheet**		**Filter**		**Agar**	**Blotter sheet**		**Filter**		**Agar**
Fungi genera	**SS**	**NSS**	**SS**	**NSS**		**SS**	**NSS**	**SS**	**NSS**	
Fusarium	41.75	61	31	66	96.5	61.75	77.25	73.5	74.5	95.8
Botryosphaeria	-	-	-	-	1.25	-	-	-	-	2.24
Alternaria	-	-	-	-	-	-	-	-	-	0.75
Aspergillus	6.25	13.25	1	12	-	3.5	4.25	0.5	0.5	-
Rhizopus	1	0.75		0.5	0.75	2	6	-	3.5	-
Nectria	-	-	-	-	0.75	-	-	-	-	-
Pestalotia	-	-	-	-	0.25	-	-	-	-	-
Total	**49**	**75**	**32**	**78.5**	**99.5**	**67.25**	**87.5**	**74**	**78.5**	**98.8**

Both seed lots of the two provenances from Kibwezi and Ikanga had storage moulds that included *Aspergillus sp* and *Rhizopus sp.* The incidence of these storage fungi was dominant in non-surface sterilized seed on blotter and filter paper compared to the agar medium. Occurrence of field fungi was dominated by *Fusarium sp* which occurred on up to 96% of the seed assayed on agar medium. Lower percentages of this fungus were encountered on blotter sheet and filter paper. Other field fungi encountered on the two provenances of *D. melonoxylon* included *Botryosphaeria sp*, *Alternaria sp*, *Nectria* sp and *Pestalotia sp*. Both provenances of this species were heavily infested with *Fusarium sp*.

Discussion

This study showed that several genera of both storage and field fungi existed on or in the seeds. Seedlots of *Grevillea robusta, Moringa oleifera* and *Dalbergia melanoxylon* assayed were all found to harbour several storage and field fungi in diverse magnitudes. The storage fungi that comprised of the genera *Aspergillus* and *Penicillium* were dominant on non-surface sterilized seed of *Grevillea robusta* and *Moringa oleifera* in blotter/filter paper tests. Their presence on Agar medium after surface sterilization was minimal. Their main effect is seed viability under prolonged storage (Sutherland *et al*., 2002)

Field fungi isolated from seed of provenances of the three species included potential pathogens that included *Fusarium* sp, *Botryosphaeria* sp, *Altenaria sp, Phoma sp, Rhizoctonia* sp, *Pestalotia sp. Grevillea robusta* and *Moringa oleifera* had mild infestation from the field fungi. Seed of the two provenances of *Dalbergia melanoxylon* tested were heavily infected with the field fungus *Fusarium* under all test conditions (96% of seed tested). Seeds of *Dalbergia sissoo,* a closely related species from India, have been shown to harbor a range of storage and field fungi (Tiwari and Sharma,1980)

Conclusion

Stored seedlots of two provenances each of *Grevillea robusta, Moringa oleifera* and *Dalbergia melanoxylon* were found to habour a range of storage and field fungi. The intensity of infection varied with the seed lots and provenances for *Moringa oleifera* and *Grevillea robusta*. The blotter/filter technique mainly yielded storage fungi. Most field fungi were isolated by the Agar plated method. *Dalbergia melanoxylon* was heavily infested by *Fusarium sp*. This study has revealed that the three species harbor seed borne mycoflora. Further studies should be undertaken on other species prone to fungal attack during germination tests.

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Viability of East African Sandalwood Seed Stored at Various Temperatures for Two Years

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Abstract

East African Sandalwood *(Osyris lanceolata)* is highly valued in the manufacturing of perfumery and medicinal products, and there is need for its domestication. Seed storage behavior was determined as the information is important in planning and implementing the species planting programmes and conservation strategies. Fresh seed and seed dried to moisture content of 7 % were placed in airtight plastic vials and stored at ambient temperature, constant temperature of 20 ^{0}C, and in a cold room set at -20 ^{0}C. At 0, 3, 9, 12 and 24 months of storage, seeds were subjected to a germination test. At months zero, dried seeds had scored better in mean parameter values for germination capacity (G), mean germination time (MT) and germination value (GV) than fresh seeds Germination capacity of seed stored fresh dropped rapidly by month 3 in all the storage environments from 69 % to mean G of between 0 and 16 % making it inconsequential to test for storability. Germination capacity of dried seed dropped gradually in all the storage environments from the initial G of 85 %. Dried seed stored at ambient and constant temperature registered G of over 70 % in 3 months and over 60 % at 3 to 9 months. By 24 months, the G dropped drastically to 21 % for seed stored at ambient and constant temperature and to 29 % for seed stored in cold room. There was significant difference in G, GV and MT ($p<0.01$) depending on the period of storage. The results indicate that Sandalwood is neither a classical recalcitrant nor orthodox and may be classified as intermediate seed storage behaviour but withstanding drying to low moisture content.

Keywords: *Osyris lanceolata*, seed storage, recalcitrant, intermediate, orthodox, seed moisture content

Introduction

East African Sandalwood (*Osyris lanceolata* Hochst. & Steud.) Is in the family Santalaceae and is a dioecious evergreen tree that grows up to a height of 6 meters. The species has a wide ecological distribution in eastern and southern Africa. It grows in diverse locations including rocky sites, along dry forest margins, evergreen bushlands, grasslands and thickets at an altitude range of 900 to 2550 m above sea level (Beentje, 1994). The species grows naturally as a parasite through root attachments on other trees such as *Dodonea viscosa*, *Searsia natalensis*, and *Carissa spinarum (*Mwang'ingo *et al*., 2005). Due to overexploitation to meet international demand for its perfumery and medicinal products, *O. lanceolata* (Osyris) has been listed as an endangered species in eastern Africa and its populations in the region are protected under the Convention on International Trade in Endangered Species (CITES) Appendix II (USF&WS, 2013).

The method for propagating Osyris through seed has been developed to help in domestication and mass planting of the species, which will subsequently ease pressure on the few remaining wild populations (Kamondo *et al*., 2012). However, information on how long seeds of Osyris will remain viable after collection is lacking, although this is important in planning and implementing planting programmes of the species.

Seeds of plants fall under three different seed storage behaviour; orthodox, recalcitrant and intermediate (Hong *et al*., 1997). Orthodox seeds can be dried to 5 % moisture content and stored for hundreds of years in airtight (hermetic) containers at -20 ^{o}C. Even at room temperature, these seeds will store for up to one year without significant loss of viability. Recalcitrant seeds do not withstand drying, and therefore can only be stored for short periods of up to 3 months, at high moisture content. Attempts to store recalcitrant seeds at below 0 ^{o}C, result in ice formation and freezing injury, which kill the seeds. Chilling injury could also occur even at relatively high temperatures of 10 to 15 ^{o}C. Intermediate seed storage behaviour is in between the orthodox and recalcitrant categories. Although the seeds withstand some form of drying, they do not tolerate extreme drying. In some cases, such seeds will store long if dried to moisture content of 10 to 12 % in hermetic containers in cold storage. In other cases, seeds will store better at room storage rather than below 0 ^{o}C.

Species with orthodox and to some extent intermediate seed storage behaviour offer more flexibility in planning and implementing planting and conservation programmes. Furthermore, orthodox seeds can be stored in genebanks for long-term conservation of the species. Planting programmes for species with recalcitrant seeds must be more accurately planned as raising of nursery stock must be closely synchronized with the fruiting season. Recalcitrant seeds cannot be stored in seed banks for long-term conservation programmes.

Studies Mwang'ingo *et al.* (2004) suggested that Osyris seed is recalcitrant. However, Osyris seeds dried to moisture content of about 7 % have resulted in high germination rate of over 70 %, raising doubts on the classification of Osyris seed as recalcitrant (Nyamongo *et al*., 2014). The objective of this study was therefore, to generate empirical data that will explain the seed storage behaviour of Osyris.

Materials and Methods

Ripe fruits were hand-picked from wild population of Osyris wild population in Kitui County and subjected to the recommended Osyris seed handling protocol for producing best grade seed (Kamondo *et al*., 2012) and used in experiment. The seedlot was then divided into two sublots referred to hereafter as 'fresh seed' and 'dry seed'. A germination test was undertaken on the fresh seed to assess initial germination. The 'dry seed' sublot was dried for three days to a moisture content of 7 % at the genebank of Kenya air-lock and a sample drawn to determine the initial germination. Both germination tests were based on 4 replicates of 25 seeds each. A germination test was conducted on sand in 4 germination trays with each tray as a replicate, and placed in a non-mist propagator with each tray holding 25 seeds. A seed was considered to have germinated immediately a germinant emerged from the sand. The number of germinated seedlings was scored daily for a period of 80 days.

Fresh seed and Dry seed sublots were packaged into airtight plastic vials and stored at;

- Ambient conditions in Kitui Regional Research Centre on the cupboard shelf
- The Gene Bank of Kenya dry-room, which is regulated at a constant temperature of 20 ^{0}C
- The Gene Bank of Kenya cold room set at -20 ^{0}C.

At 3, 9, 12 and 24 months of storage, seeds from both sublots were subjected to a germination test using same testing environments as for the previous germination except that the number of seeds used were reduced to 75 due to limitation of seed quintiles, and replicated in 3 germination trays with each tray holding 25 seeds. The number of seedlings germinated was scored daily from the day of initial germination for a period of 80 days.

Data analysis

The benchmark germination curves were superimposed on germination curves of stored seeds to graphically show the effect of time and environment. The resultant germination curves guided the identification of datasets that required further analysis for statistical significance. The germination processes were compared for statistical significance using parameters associated with seed germination. Germination capacity (G), mean germination time (MT), and germination value (GV) and their means and variances were used to test for statistical significance. The template published by Marli *et al*. (2009), was used to ensure correct calculations of mean germination time (MT). The germination process parameters for testing significance were calculated and analyzed as follows:

Germination capacity

Germination capacity is the proportion of a seed sample that has germinated normally in a specified test period, usually expressed as a percentage. The differences in germination capacity among the treatment means were tested through factorial analysis on the arcsine transformed germination percentages. When comparing seedlots, high germination capacity is indicative of higher quality seedlots.

Germination value

Germination value is a composite value that combines both germination speed, which was obtained by dividing cumulative germination percentage by number of days or specified time interval, and total germination. The germination value was calculated according to the formula published by Diavanshir and Porubeik (1976) as follows:

$$GV = (\sum DGs/N) \times GP/10$$

Where:

GV is germination value,

GP is germination percentage at the end of the test period

DGs is Daily germination speed obtained by dividing the cumulative germination percentage by the number of days since sowing

N is the total number of daily counts, starting from the date of first germination

10 is a constant.

In each germination test, germination values were calculated for each day commencing on the day of germination to the end of the testing period of 80 days. The maximum germination value was taken as the true germination value for the respective germination test as guided by Diavanshir and Porubeik (1976), and was used to make comparisions of treatment effects. High germination value denotes higher quality seed.

Mean germination time

The mean germination time is a measurement of the average length of time required for maximum germination of a seedlot (Marli and Santana, 2006), and was expressed in days corresponding to the same units of time used in counting germination. The mean germination time $\bar{t}$ was calculated according to Marli *et al*., (2009), with the expression:

$$\bar{t} = \frac{\sum_{i=1}^{k} n_i t_i}{\sum_{i=1}^{k} n_i}$$

Where t_i: time from the start of the experiment to the i^{th} observation; n_i: number of seeds germinated in the i^{th} time, and k: last time of germination (Marli *et al*., 2009). When comparing two seedlots, the seedlot with lower mean germination time is indicative of higher quality seed.

Results

Benchmark germination results

Fresh seed germinated from day 28 reaching peak germination of 69 % on day 61, while dry seed germinated from day 21 reaching peak germination of 85 % on day 51 (Figure 1). Germination for dry seeds, showed better mean values for germination rate (G), mean germination time (MT) and germination value than fresh seeds (Table 1).

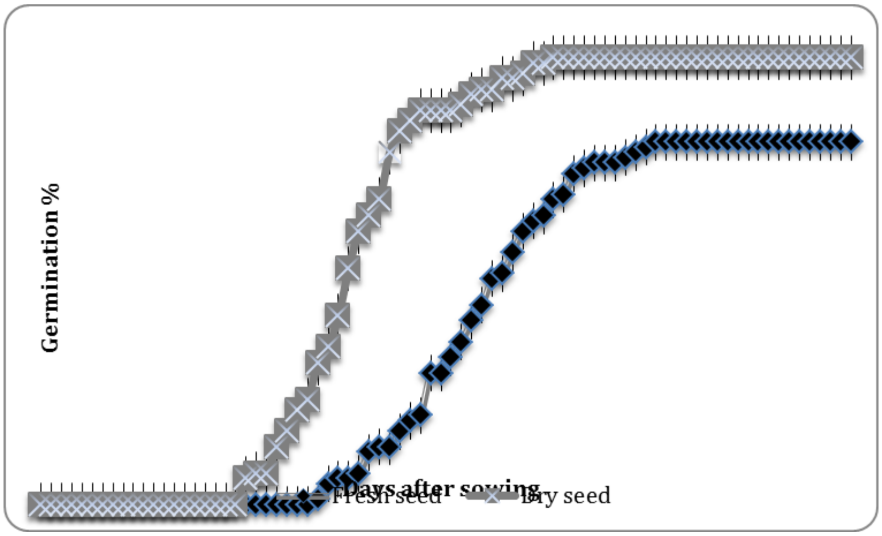

Figure 1. Germination trends (means and standard error) for fresh and dry *Osyris lanceolata* seeds at zero months

Table 1. Bench mark germination rate (G), mean germination time (MT), and germination value (GV) of *Osyris lanceolata* seeds

Seed category	Rep	n	G	MT	GV
Fresh seed	1	25	68	48.5	5.6
	2	25	60	44.1	4.4
	3	25	68	39.5	6.6
	4	25	80	41.7	9.0
	Means		69	43.4	6.4
Dry seed	1	25	92	29.8	15.69
	2	25	64	33.3	7.04
	3	25	96	33.7	14.36
	4	25	88	31.3	13.66
	Means		85	32.0	12.69

There was significant difference in germination capacity between fresh seed and dried seed (Figure 1). There were also significant differences ($p<0.05$) in germination value between fresh seed and dried seed at zero months (Table 2). The dried seeds showed significantly higher (double) GV compared to fresh seed. Similarly, Mean Germination time (MT) also differed significantly between fresh and dried seed at zero time, but MT mean value was higher in fresh compared with dry seed.

Table 2. Analysis of variance (ANOVA) for GV and MT for *Osyris lanceolata* seed sublots at zero months

	GV			MT		
Source of variation	DF	MS	F	DF	MS	F
Rep	3	13.345	2.44	3	3.86	0.27
Seed sublots	1	79.596	14.53*	1	260.3	18.22*
Residual	3	5.477		3	14.27	

Germination trends in seed stored fresh and dried

Germination of seed stored fresh dropped rapidly over time in all the storage environments registering germination lower than 10 %, except for seed stored in the cold room at three months, which registered a germination of 16 % (Table 3). As germination capacity of seed stored fresh in any of the environment was poor, the germination process of these seeds was not subjected to any further scrutiny.

Table 3. Mean germination capacity (%) of fresh *Osyris lancelota* seeds stored at ambient, dry room and in cold room conditions for 0, 3, 9, 12 and 24 months

Storage environment	0 months	3 months	9 months	12 months	24 months
Ambient	69	5.3	0	0	0
Dry room	69	2.7	0	0	0
Cold room	69	16.0	1.3	1.3	0

Germination of seed stored dry dropped over time in all the storage environments from the benchmark germination of 85 %. Seed stored in the cold room registered the highest drop at each trial period. Whereas seed stored at ambient and dry room conditions registered germination of over 70 % in 3 months and over 60 % at 3 to 9 months, seeds stored in the cold room registered germination of 60 % and over 56 % for the same periods. By 24 months, the germination capacity dropped drastically to around 21 % for seed stored at ambient and dry room conditions and 29 % for seed stored in cold room (Table 4).

Table 4. Mean germination capacity (%) of dry seeds stored at ambient, dry room and in cold room conditions for 0, 3, 9, 12 and 24 months

Storage environment	0 months	3 months	9 months	12 month	24 month
Ambient	85	76.0	69.3	65.3	21.3
Dry room	85	73.3	68.0	68.0	21.3
Cold room	85	60.0	56.0	50.7	29.3

At 3 months, seed stored at ambient and dry room conditions had similar mean germination time of about 45 days, while seed stored at the cold room had a lower mean germination time of 35 days. At 9 and 12 months, the range in mean germination time narrowed among the seedlots to no more than 5 days with the highest MT being about 33 days at dry room for 12 months and lowest being about 29 days at ambient temperature for 9 months. At 3 and 12 months, the highest germination value was for seeds stored at the cold room while, at 9 months, seeds stored at ambient conditions had highest GV. Seeds stored at dry-room temperature had the lowest GV for all the storage periods. There were significant differences in germination capacity for different storage time ($p<0.01$) (Table 5). When mean separation was undertaken, it was established that the difference in germination was between the germination at 24 months and the germination at the rest of germination time (Table 6). There were significant differences in germination value for different storage time. There were also differences in storage environment ($p<0.01$). The storage environment marginally affected GV at different storage times ($p=0.05$) (Table 7). Further analysis showed that the differences in GV was due to storage time and also due to storage environment were mainly as a result of differences between 24 months and the rest of the storage times (Table 8).

Table 5. Analysis of variance of germination capacity for dried *Osyris lanceolata* seed stored at ambient, dry room and in cold room conditions for 0, 3, 9, 12 and 24 months

Source of variation	DF	MS	F pr.
Block stratum	2	268.44	
Storage time (ST)	3	3925.93	<.001
Storage Environment (SE)	2	312.44	0.017
ST*SE	6	131.70	0.097
Residual	22	63.35	

Table 6. Mean separation of germination capacity of dried *Osyris lanceolata* seed stored for 3, 9, 12, and 24 months.

Storage time in months	N	Subset	
		1	2
24	9	24.000	
12	9		61.333
9	9		64.444
3	9		69.777

Table 7. Analysis of variance of GV for dried *Osyris lanceolata* seed stored at ambient, dry room and in cold room conditions for 0, 3, 9, 12 and 24 months

Source of variation	DF	MS	F
Block stratum	2	0.3249	2.17**
Storage time (ST)	3	5.2056	34.84**
Storage Environment (SE)	2	1.4788	9.90**
ST*SE	6	0.3698	2.47*
Residual	22	0.1494	

Table 8. Mean separation according to significance in effect of storage time on GV using Tukey's b test

Storage time (Months)	N	Subset	
		1	2
24.0	9	0.23438	
12.0	9		1.72818
3.0	9		1.73012
9.0	9		1.80319

Results also indicated highly significant differences in MT for different storage time and storage environment ($p<0.01$) (Table 9). There is an interaction between storage time and environment implying storage environment influenced MT at different storage times.

Table 9. ANOVA of MT for dried *Osyris lanceolata* seed stored at ambient, dry room and in cold room conditions for 0, 3, 9, 12 and 24 months

Source of variation	DF	MS	F
Block stratum	2	23.391	3.08
Storage time (ST)	3	277.469	36.58**
Storage Environment (SE)	2	49.479	6.52**
ST*SE	6	34.600	4.56*
Residual	22	7.586	

Discussion

Benchmark germination results indicated that germination capacity of Osyris seed and germination value improved with drying and that the seed could withstand drying to moisture content of less than 10%. Maintenance of viability of seed with drying to moisture content of less than 10% is characteristic of orthodox seed (McDonald, 2004). The storage experiment established that fresh Osyris seeds, when stored rapidly lose viability. This result is inconsistent with Mwang'ingo *et al*. (2004), who reported a limit of 20 % moisture content for maintenance of seed viability for the species during seed storage, suggesting the seed to be recalcitrant. Recalcitrant seeds are sensitive to desiccation and freezing (Berjak and Pammenter, 2004; McDonald, 2004). Death of recalcitrant seeds due to loss of moisture is mainly attributed to the loss of membrane integrity and nuclear disintegration (Chin, 1995)

Dried Osyris seeds maintained good germination rates, mean germination time and germination value for the first year, even when stored in subzero temperature, but the seed viability plummeted when tested after two years. Orthodox seed are expected to maintain viability in storage for a long time, with true orthodox seeds known to withstand sub-freezing temperatures for long periods, up to several decades when dried to 10 % or less moisture content (Bonner 1990, Mng'omba *et al*., 2007). The results therefore indicated that Sandalwood is not a true orthodox seed.

Based on our findings, we classify *Osyris lanceolata* seed as intermediate seed that benefit from drying to low temperatures and storing in either cold or ambient temperatures. Although we classify Osyris seed as intermediate, it is noted that the behaviour of the seed is not fully in conformity with the definition of this category of seed, as Osyris seed withstand drying to the same levels as that used in storing of orthodox seed. According to Andrade *et al*. (2003), intermediate seeds are relatively desiccation-tolerant, but will not withstand removal of water to levels as low as orthodox seeds. These species, particularly if they are of tropical origin, may also be chilling-sensitive, even in the desiccated state (Hong and Ellis, 1996; 1998).

Conclusions and recommendations

Sandalwood seed should be dried to moisture content of less than 10% to improve germination capacity. As dried Osyris seed tolerate storage in ambient temperature, this makes it easy to store, as it does not require any sophisticated storage facilities. However, the limited time of seed storage of about one year indicated that the seed planting programmes cannot be based on storing of large quantities of seed for a long period of time, as any seed stored for more than one year would have low viability. Planting programmes for Sandalwood would therefore benefit by careful estimation of annual seedling demand and matched with annual seed collection activities that also consider the seed productivity of the seed sources. The results also show that Osyris is not amenable to long-term seed conservation in cold rooms.

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Tracking the Bronze Bug Invasion in Eucalypts Plantations in Kenya

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Abstract
The winter bronze bug *Thaumastocoris peregrinus*, is globally a highly invasive pest of *eucalypts*. The pest is currently posing a severe threat to the productivity of Africa's eucalypts planted forests and has been spreading in Kenya since 2009. Understanding the distribution and ecology of invading bronze bug populations is a crucial step in designing the pest's management strategies. The study characterized current *T. peregrinus* distribution and infestation levels in Kenya by conducting a 4-year survey in key eucalypts growing areas. Insect populations initially proliferated within the central highlands, a second outbreak invaded the coastal region two years after detection, and by the third year, most Kenya's eucalypts growing areas were infested. Pest occurrence steadily increased in the first three years, and eventually reached 70 % of infested plots. Infestations worsened dramatically during the fourth year of observation, with the proportion of un-infested plots dropping after one year and the proportion with more than 75 % of infested trees increasing significantly after two years. The study presents the first account of the invasive bronze bug expanding its non-native range in Eastern Africa. The study also provides valuable information for implementing a classical biological control programme and protecting East Africa's eucalypts resources.

Keywords: *Thaumastocoris peregrinus*, eucalypts, forest pest, mapping, pest management, invasion.

Introduction

Africa's planted forests are increasingly being threatened by emerging insect pests and microbial pathogens (Wingfield *et al.*, 2015, Hurley *et al.*, 2017), thus disrupting the forests' natural processes and ecosystem services (Boyd *et al*., 2013; Liebhold *et al.*, 2017). For example, a complex of pathogenic *Botryosphaeriaceae* species is causing dieback to the Australian silk oak

Grevillea robusta in East Africa (Njuguna *et al*., 2011). Furthermore, *Eucalyptus* plantations in Eastern African countries are under attack by a newly detected canker disease (Machua *et al*., 2016), and a plethora of highly invasive herbivorous insects including non-native Blue gum chalcid *Leptocybe invasa* (Hymenoptera: Eulophidae), Red gum lerp psyllid *Glycaspis brimblecombei* (Hemiptera: Psyllidae), and Bronze bug *Thaumastocoris peregrinus* (Hemiptera: Thaumastocoridae) (Nyeko *et al*., 2010; Paine *et al*., 2011; Hurley *et al*., 2016). The proliferation and impact of these organisms could frustrate the overall benefits of major agroforestry and forestry programmes in Sub-Saharan Africa.

Eucalyptus spp. is widely grown in East Africa for firewood, poles and various products due to its fast growth and tolerance to environmental stresses (Oballa *et al*., 2010; Langat *et al*., 2015). Its cultivation has helped reduce production of wood energy from natural forests and provides income for smallholder farmers, thus contributing to mitigating deforestation and reducing poverty in marginal lands (Louppe and Depommier, 2010). *Eucalyptus* spp. Have been commonly grown across Kenya's agro-climatic zones since the early 1990's, when technical advances in selection, breeding, and propagation of planting material were made available (Wingfield *et al.,* 2008). The most widely cultivated species are *Eucalyptus camaldulensis, E. globulus, E. saligna, E. regnans, E. grandis*, and several *E. grandis x E. camaldulensis* hybrid clones including GC10, GC522 and GC15 (Oballa *et al*., 2010). About 150,000 ha of over 40 *Eucalyptus* species and hybrid clones are currently grown in the country (Otieno *et al*., 2009; Oballa *et al*., 2010).

The bronze bug *Thaumastocoris peregrinus* Carpintero and Dellapé (Hemiptera: Thaumastocoridae) is a highly invasive, phloem-feeding insect pest of *Eucalyptus* spp. that has successfully invaded the world's major growing areas of this tree, from temperate to tropical, subtropical and arid regions. Native to Southwestern Australia, the insect is currently spreading as a non-native invasive in Africa, South America, Europe and New Zealand (Carpintero and Dellapé, 2006; Nadel *et al*., 2010; Noack *et al*., 2011; Laudonia and Sasso, 2012; Nadel and Noack, 2012; Garcia *et al*., 2013). Following its first detection in the African continent in 2003 in Gauteng Province, South Africa, the insect initially proliferated locally, but then spread northwards reaching Zimbabwe (2007), Malawi (2008), Tanzania (2009), Kenya (2009) and Uganda (2010) (Nadel *et al*., 2010, Montemayor *et al.*, 2015). The bronze bug was detected in Kenya in November 2009, infesting a newly planted *E. grandis* plot in Kajiado county (Mutitu, unpublished data).

Thaumastocoris peregrinus feeds on leaves and twigs of over 30 *Eucalyptus* species and hybrids, (Noack *et al*., 2011; Nadel *et al*., 2012), causing the foliage to turn reddish-yellow and yellow-brown as the infestation progresses (Jacobs and Neser 2005; Wilcken *et al*., 2008; 2010; Soliman *et al*., 2012). Bronze bugs are gregarious, with nymphs and adults visible on host foliage. Highly infested trees drop their leaves, thus reducing tree growth and eventually triggering mortality

(Noack and Rose, 2007; Nadel *et al*., 2010; Soliman *et al*., 2012). High reproductive potential, short life cycle, and the ability to cling on surfaces tenaciously due to enlarged apical tibial appendices contribute to *T. peregrinus* dispersal ability and invasiveness (Carpintero and Dellapé, 2006; Noack *et al.*, 2011).

The management of bronze bug outbreaks is challenging, as the use of neonicotinoid insecticides is not sustainable at large scale and host resistance is still marginally explored (Noack *et al*., 2007; Noack *et al*., 2011; Mutitu *et al*., 2013). Recently, the egg parasitoid *Cleruchoides noackae* Lin and Huber (Hymenoptera: Mymaridae) has been identified in *T. peregrinus* native range and evaluated for classical biological control. The wasp was released in South Africa, Chile and Brazil and its impact is being assessed (Mutitu *et al*., 2013; Souza *et al*., 2016).

Bronze bug outbreaks pose a serious threat to the productivity and overall sustainability of eucalypts cultivation in Kenya, and may represent a destabilizing factor for the economic development of rural communities. Understanding the distribution and occurrence of invading *T. peregrinus* populations in the country is a crucial step in developing appropriate management strategies, including biological control. In light of this, a study was undertaken to (a) characterize current *T. peregrinus* occurrence in the major eucalypts growing areas in Kenya, and (b) assess local pest incidence levels over the 4 year period following first detection in the country.

Materials and methods

Annual survey were conducted from 2010 to 2013 to assess bronze bug infestations on *E. camaldulensis*, *E. grandis* and *E. urophylla* and associated hybrid clones in Western, Rift Valley, Central, South Eastern and Coastal regions of Kenya. One to six year old *Eucalyptus* woodlots were selected and two linear transects of 25 trees per woodlot conducted, one on the windward edge and the other running across the woodlot. Geographic coordinates, elevation, tree species and age for each woodlot were also recorded. Geo-referred survey data were managed with ESRI Arc GIS, version 10.5 to prepare maps.A total of 287 woodlots were sampled; 95 in 2010, 24 in 2011, 79 in 2012, and 89 in 2013. Trees were assessed for presence of all life stages of the insect by inspecting foliage about 2 metres from the ground. Bronze bug presence were determined and plots categorized in four incidence classes: absent (0 % infested trees), low (0.1 to 35 %), moderate (35.1 to 75 %), and high (>75 % infested trees).

Analysis of Variance (PROC MIXED SAS Version 12.1) was used to test differences in plot-level bronze bug occurrence and incidence classes over time. Pest presence and incidence class data were Arcsine transformed to meet normality assumptions.

Results

Following the initial infestation detected in Kajiado County in November 2009, bronze bug populations began spreading within the Central Highlands and reached Western and Coastal region by 2011. A second invasion front was detected in the coastal region in 2011, and the invasion progressed northwards, colonizing Kenya's major *eucalypts* growing areas the following year (Fig. 1). Pest occurrence dramatically increased from 2 % in 2010 to 54 % in 2011, eventually levelling-off to approximately 70 % of infested plots in 2012 (Figure 2).

Similarly, pest incidence increased in 2011, two years after initial detection, with highly infested plots increasing from 0 % to 8 % in 2011, and reaching over 20 % in 2012 (Figure 3). The highest levels of incidence were detected within central highlands and western regions, while the coastal region showed low and moderate infestations (Figure 1).

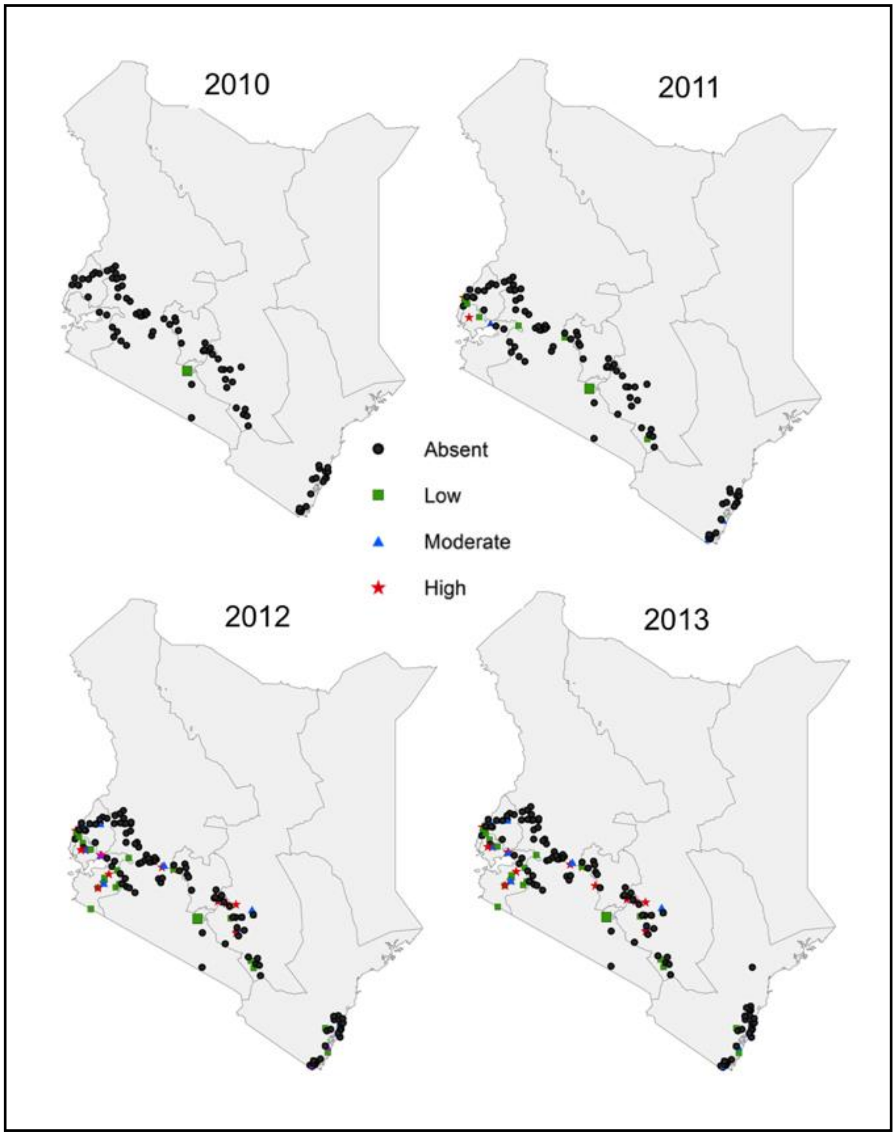

Figure 1. Occurrence, distribution and incidence levels of *T. peregrinus* in Kenya from 2010-2013. Pest incidence classes: absent (0 % infested trees), low (0.1-35 %), moderate (= intermediate) (35.1-75 %), high (>75 %).

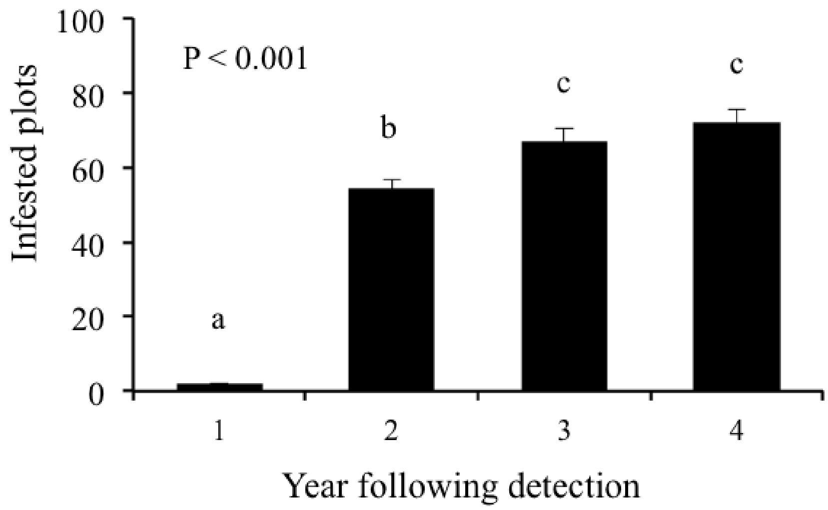

Figure 2. Occurrence of *T. peregrinus* in Kenya in the four years following detection (2010 to 2013). Means followed by the same letter do not differ significantly (α = 0.05).

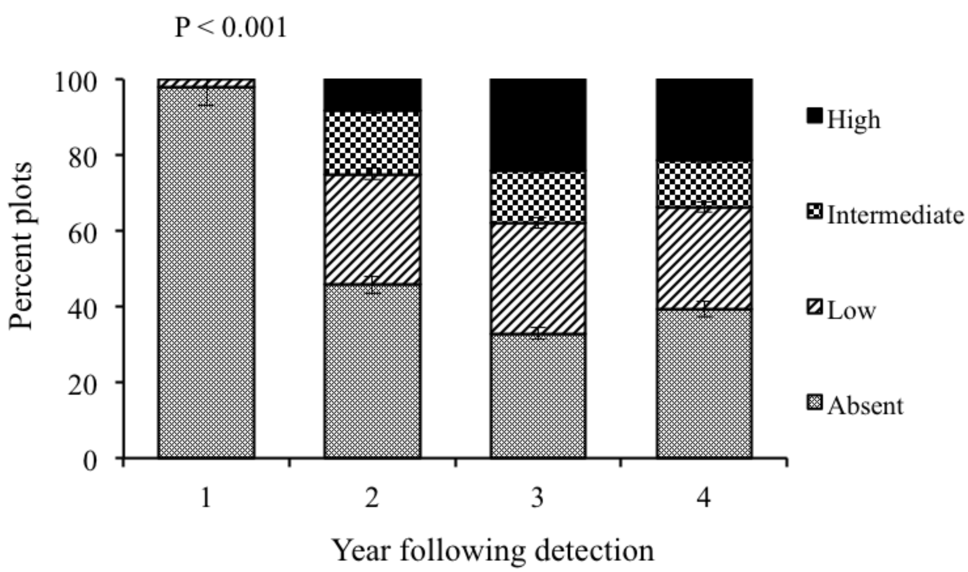

Figure 3. Variation of incidence levels of *T. peregrinus* in Kenya in the four years following detection (2010 to 2013). Pest incidence classes: absent (0 % infested trees), low (0.1 to 35 %), moderate (= intermediate) (35.1 to 75 %), high (>75%).

Discussion

This study presents the first detailed description of *T. peregrinus* occurrence in Kenya and reveals the invasion progression of a destructive herbivorous insect, expanding its invasive range in planted forests in Kenya. The insect reached most major *eucalypts* growing areas in the country within four years of introduction, and the severity of infestations is progressively increasing. Considering that Kenya and Tanzania were the first East African countries to be invaded by the insect after detection in Southern Africa (Nadel *et al.*, 2010, Montemayor *et al.*, 2015), it can be hypothesized that the introduction in Kenya may have been accidental through plant material, or due to natural spread from undetected infestations in neighbouring countries such as Tanzania or Uganda, that served as "bridgeheads" (Lombaert *et al*., 2010; Garnas *et al*., 2012; Hurley *et al*., 2016).

After its arrival in central-southern Kenya, the invasion progressed mostly in the Central Highlands and western regions, but an additional invasion front was observed in 2010 on the southern coastal area. This illustrates that *T. peregrinus* is invading Africa according to a stratified dispersal model, with long range aided by wind, animals and human activities, and short distance movement due to active dispersal, and is expected to expand further (Nadel *et al*., 2010; Montemayor *et al*., 2015). In addition, the nearly continuous distribution of the host across Kenyan landscapes facilitated population proliferation and resulted in quick invasion.

The rapid spread observed in Kenya is comparable to the approximately three years required by *T. peregrinus* to invade South Africa after first reports in 2003 (Jacobs and Nesser, 2005; Nadel *et al*., 2010). Other non-native insect pests have been reported to colonize African landscapes following a similar pattern, including the Mediterranean pine engraver beetle *Orthotomicus erosus* (Coleptera: Curculionidae) and Sirex woodwasp *Sirex noctilio* (Hymenoptera: Siricidae) affecting pine resources in South Africa; and the blue gum chalcid *L. invasa* colonizing *Eucalyptus* spp. (Tribe and Cillié, 2004; Garnas *et al*., 2012, Hurley *et al*., 2016). In particular, the bronze bug colonized Kenya according to a dispersal pattern comparable to the one shown by the blue gum chalcid, with both active and passive dispersal allowing short and long distal movement, thus resulting in a very rapid colonization of eucalypts resources and fast population build-up (Mutitu *et al*., 2007; Nyeko *et al*., 2009; Zheng *et al*., 2014).

The invasion history of these destructive non-native pests and the arrival of *T. peregrinus* in East Africa only six years after detection in South Africa also highlight the challenge in implementing quarantine regulations with equal effectiveness in different countries across the continent, and globally (Garnas *et al*., 2012; Nadel *et al*., 2014; Hurley *et al*., 2016). The availability of eucalypts hosts across Africa will also enhance the pest invasiveness, and populations of bronze bug. Species with similar host range such as the blue gum chalcid are expected to spread further throughout the continent. Therefore, a regional strategy is urgently required to coordinate monitoring and management efforts (Garnas *et al*., 2012, Wingfield *et al*., 2015).

The knowledge on pest distribution and severity generated in this study will be essential for continuing surveys to assess impact on eucalypts productivity, and for implementing pest awareness campaigns. Furthermore, this information will be used as baseline for activating locally appropriate management responses, and in particular for developing classical biological control programs such as the one based on the egg parasitoid *Cleruchoides noackae* (Nadel *et al.*, 2012; Mutitu *et al.*, 2013). A detailed map of *T. peregrinus* occurrence and infestation severity will allow the planning of effective biocontrol releases.

In light of this, these findings should be followed by additional studies aimed to evaluate *T. peregrinus* population dynamics and seasonal abundance in Kenya (Nadel *et al*., 2014) and the role of Eucalypts cultivars in modulating both pest and parasitoid performance.

Acknowledgements
We wish to thank Emily Yobterik and George Opondo for assistance in field, laboratory and data management. We are grateful to farm owners for collaboration during the surveys: Violet Farm in Kiserian, Kajiado County; Gicheha Farm in Ruiru, Kiambu County, and Mukeu, Mitumbiri, Kakuzi and Aberdare Farms in Muranga County. The Government of Kenya through the Kenya Forestry Research Institute funded this work.

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Diversity and Activity Density of Insects on Avocado Flowers in Kandara, Murang'a County

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Abstract

Avocado (*Persea americana*, Lauraceae) is an important economic crop in Kenya grown for domestic and export market. Pollinators are essential for fruit production, and are managed in developed countries, which is not so in Kenya. This study was carried out to determine diversity and activity density of avocado flower visiting insects in farmers' fields at Kandara, Murang'a County. Twelve farms were randomly selected for the study. In each farm, five mature avocado trees were selected. A minimum distance of about 10 m and 200 m was maintained from tree to tree and farm to farm, respectively. Data collection started when 10 % or more of the plants had started to bloom for three blooming seasons. Observations were done for 10 minutes in every tree in each farm, weekly throughout the blooming period, under good weather conditions between 0900 h and 1700 h. Data included the flower visitors' identity and their numbers per species. Data was analyzed using Shannon-Wiener index. Various insects visited avocado flowers. They included Hymenopterans (91.43 %), Dipterans (8.35 %), Lepidopterans (0.17 %) and Coleopterans (0.06 %). Honeybees had the highest activity density (87.31 %), blow flies (5.3 %), hoverflies (3.05 %) and wasps (2.71 %) of the flower visitors. The pollination diversity index and evenness were 0.25 and 0.11 respectively. The findings are important in pollinators' conservation, monitoring and management. The study confirmed that honeybees are important avocado flower visitors. We recommended that beehives be placed in avocado orchards for increased pollination, to improve avocado yields.

Keywords: Activity density, blooming period, diversity, evenness, pollination

Introduction

Avocado (*Persea americana)* is an important crop in many tropical and subtropical regions around the world (Knight, 2002). It is one of the oily fruits grown in Kenya for the fresh market and oil production. Hass and Fuerte are the two major commercial varieties of avocado grown in Kandara, Muranga County for both consumption and export. Avocado farming has improved the livelihoods of the local farmers in Kandara through creation of employment opportunities especially through contract farming (Mwambi *et al.*, 2013).

In countries such as Israel, California and South Africa, pollination is classified as a major limiting factor of avocado production (Ish-Am, 2005; Ish-Am and Lahav, 2011), and therefore, considerations are put in place for its management. However, managed pollination using honey bees does not completely address avocado pollination provision in these countries (Vithanage, 1990; Ish-Am and Eisikowitch, 1998; Gazit and Degani, 2002).

Wide diversity of insects is reported to contribute to higher avocado yields (Balam *et al.*, 2012). Some of these insects include honey bees (*Apis mellifera* L.), flies *(Chrysomya megacephala)*, native wasps *(Brachygastra mellifica)*, stingless bees (*Apidae, Meliponinae*), the *Bombus spp.* and even thrips (Gazit and Degani, 2002; Wysoki *et al.*, 2002; Can-Alonzo *et al*., 2005; Afik *et al*., 2006; Gazit and Ish-Am, 2006; Ish-Am and Lahav, 2011; Balam *et al.*, 2012). Diversity of pollinating insects is credited for effective pollination provision, possibly through increased competition for floral resources and complementary role (Gikungu, 2006; Greenleaf and Kremen, 2007; Carvalheiro *et al.*, 2011).

Increasing or maintaining high pollinator diversity is known to enhance yield quantity and stability by improving the pollination efficiency of honey bees (Greenleaf and Kremen, 2006) and reduce the risk of pollination failure due to climate change (Rader *et al.*, 2013; Bartomeus *et al.*, 2013), or environmental disturbances such as extreme weather events (Brittain *et al.*, 2012). Non-bee pollinators including flies, beetles, moths, butterflies, wasps, ants, birds, and bats, among others perform 25–50 % of the total number of flower visits (Rader *et al.*, 2016).
This study was carried out to assess diversity and abundance of the flower visiting insects on avocado.

Materials and Methods

This study was carried out in farmers' fields at Kandara (36^{o}51'E, 37^{o}7'48"E and 0^{o}47'24"S, 0^{o}58'12"S) in Murang'a County. Twelve farms were randomly selected in Kawendo area which is in *Upper Midland 2 (*UM2) agro-ecological zone of Kandara and leads in production of avocado for export. A total of five mature avocado trees (variety Hass) were randomly selected in each farm where a minimum distance of about 10 m and 200 m was maintained from tree to tree and farm-to-farm, respectively. Data in all the farms and trees were collected for three flowering seasons between September 2015 and October 2016. On each tree, observations were done for about 10 minutes in every farm, weekly throughout the blooming period. Data collected included identity of flower visitor and number of individuals observed per each visiting per species. The observations were done only under good weather conditions: temperature of 15°C and above, low wind velocity, no rain, and dry vegetation (Westphal *et al.*, 2008) between 0900 h and 1700 h. Data collection was done from the onset of the main blooming period, that is, when 10 % or more of the plants had started to bloom. Diversity index was calculated by - [$\sum$ Pi ln Pi] where P_i is the proportion of each species in the sample and $\ln P_i$ = natural logarithm of this proportion. Evenness was determined by diversity index divided by ln(N); where N is the number different insect species.

Data on the insect species visiting avocado flowers and number of each species were collected and entered into excel data sheets for analysis. Tables on pollinator abundance and diversity were created and data were analyzed using Shannon - Weiner Index for species richness and evenness.

Results

The results showed that various insects visited the avocado flowers. These included: Hymenopterans (91.43 %), Dipterans (8.35 %), Lepidopterans (0.17 %) and Coleopterans (0.06 %). Activity densities for honeybees (87.31 %), blow flies (5.30 %), hoverflies (3.05 %) and wasps (2.71 %) were documented as the four major avocado flower visitors in Kandara. Others included ants (0.73 %), Meliponula bees (0.45 %), Halictus bees (0.23 %), butterflies (0.16 %) and beetles (0.06 %).

Table 1. Avocado flower visitors' diversity and abundance for 3 seasons in Kandara, Murang'a County

Order	Species/common name	Total observations	%
Hymenoptera	*Apis mellifera* (Honey bee)	1548	87.31
Diptera	*Chrysomya putoria* (Blow fly)	94	5.3
Diptera	*Eristalis tenax* (Hoverfly)	54	3.05
Hymenoptera	*Polistes/Ammophila sp.* (Wasp)	48	2.71
Hymenoptera	*Iridomyrmex reburrus* (Ant)	13	0.73
Hymenoptera	*Meliponula ferruginea* (Meliponula bee)	8	0.45
Hymenoptera	*Halictus species* (Sweat bee)	4	0.23
Lepidoptera	*Drypta ruficollis* (Butterfly)	3	0.16
Coleoptera	*Colias electo* L. (Formicoma beetle)	1	0.06
Total		1773	100

Among the nine species observed on avocado flowers in Kandara, two species were in order Diptera and five species in the order Hymenoptera. Individuals from these two orders contributed to over 99 % of the flower visitors' abundances. Others included one species each in orders Lepidoptera and Coleoptera. The pollination diversity index and evenness were 0.25 and 0.11 respectively which were very low (Table 2).

Table 2. Diversity index and evenness of the avocado flower visitors in Kandara, Murang'a County

Species	Common name	Total No combined(Ni)	Pi	ln Pi	- (P_i * ln P_i)
Apis mellifera	Honeybee	1548	0.873096	-0.05894	0.051459
Chrysomya putoria	Blow fly	94	0.053017	-1.27558	0.067628
Eristalis tenax	Hoverfly	54	0.030457	-1.51631	0.046182
Polistes/Ammophila sp.	Wasp	48	0.027073	-1.56747	0.042436
Iridomyrmex reburrus	Ant	13	0.007332	-2.13477	0.015653
Meliponula ferruginea	Meliponula bee	8	0.004512	-2.34562	0.010584
Halictus species	Sweat bees	4	0.002256	-2.64665	0.005971
Colias electo L.	Butterfly	3	0.001692	-2.77159	0.00469
Drypta ruficollis	Formicoma beetle	1	0.000564	-3.24871	0.001832
		1773	1		0.246434

A diversity index is a quantitative measure that reflects how many different types (such as species) are there in a dataset (a community), and simultaneously takes into account how evenly the basic entities (such as individuals) are distributed among those types. Typical values are generally between 1.5 and 3.5 in most ecological studies, and the index is rarely greater than 4. The Shannon index (H) increases as both the richness and the evenness of the community increase. It is another *index* that is commonly used to characterize species *diversity* in a community. It accounts for both abundance and evenness of the species present. Evenness assumes a value between 0 and 1 with 1 being complete evenness.

Discussion

Several insects were found visiting avocado flowers in Kandara. These included Honeybees, house flies, hoverflies, wasps, ants, stingless bees (*Meliponula sp*. and *Halictus sp*.), butterflies and beetles. This is in agreement with other findings that avocado pollination is effected by insects from different taxa (Gazit and Degani, 2002; Wysoki *et al.,* 2002; Can-Alonzo *et al*., 2005; Afik *et al*., 2006; Gazit and Ish-Am, 2006; Ish-Am and Lahav, 2011; Balam *et al.,* 2012;) and flower pollination is effected by different insect species (Klein *et al.,* 2007). Honey bees were the most active insects observed visiting the avocado flowers during the study period. Such observations were made by Gazit and Degani (2002), Ish-Am (2005) and Ish-Am and Lahav (2011) that honey bees are the main pollinators in most agricultural landscapes.

Conclusion and Recommendations

This study confirmed that honey bees are important visitors of avocado flowers. blow flies, hoverflies and wasps could also be effective pollinators especially when honey bees' visitation is low. Based on the evidence, it is recommended that beehives be placed in avocado orchards for increased pollination, to improve avocado yields. We also recommend that pollen load studies for each main species observed visiting avocado flowers be determined to differentiate the avocado flower visitors from pollinators since not all flower visitors are pollinators. This, combined with visitation rates, will form an understanding of the most efficient and effective pollinator of avocado in Kandara. There is need to conserve the natural habitats for non-managed flower visitors, that may be useful when honeybees are not available due to either decreasing populations or their inability to visit avocado flowers when more desirable flowering plants are in season and are more competitive than avocado flowers. In addition to honey bee hives, stingless bees could be domesticated and hives brought into the farms for substituting and complementing the honey bees when they are unable to visit avocado flowers. Continuous monitoring of avocado flower visitors' populations within Kandara and the whole of Kenya is necessary. This will help in understanding the pollinators' stability and dependency for even other crops in Kenya. These will be useful for the purposes of pollination management planning and policy formulations.

Acknowledgement

This study was made possible by the Government of Kenya through the Horticulture Research Fund (under the Horticultural Crops Directorate) Award to Fruit Fly Project (PI Dr. Muo Kasina). We thank Kandara farmers for their willingness to allow us use their farms for this study. We finally thank Kenyatta University and KALRO management for technical and administrative support offered during this study.

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Effect of Combining Organic Materials with Urea on Striga Infestation and Maize Grain Yields in Western Kenya

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Abstract

Declining soil fertility and *Striga hermonthica* (Del) Benth infestation are serious threats to sustainable maize production in western Kenya. Appropriate soil fertility regimes are therefore critical for Striga management and improved maize productivity. This study investigated the feasibility of using sole organics or their combinations with urea on striga infestation and maize productivity on a Ferralsol in western Kenya. Urea and Calliandra or maize stover were combined in a way so as to supply nitrogen at 75 kg ha^{-1} from both sources in 0:0, 100:0, 80:20, 60:40, 40:60, 20:80, 0:100 ratios. A randomized complete block design (RCBD) with 12 treatments replicated four times was used with maize hybrid (WS 502) as a test crop. A control treatment where no nutrient inputs were applied was included. Calliandra (45 kg N ha^{-1}) combined with urea 30 kg N ha^{-1}) and maize stover at 15 kg N ha^{-1}) combined with urea 60 kg N ha^{-1} had consistently lower striga infestation compared to all other treatments. These treatments reduced striga probably due to the combined effects of suicidal germination of the *Striga* seed and increasing inorganic (N) in the soil which has a negative effect on striga. The highest maize grain yield (3.0 t ha^{-1}) was obtained in the plots where maize stover (30 kg N ha^{-1}) was combined with urea (45 kg N ha^{-1}) followed by Calliandra (45 kg N ha^{-1}) combined with urea 30 kg N ha^{-1}) with 2.7 t ha^{-1}. The two treatments increased maize grain yields by 42 and 28 % respectively against sole urea and 114 % and 92 % against the control. This could be attributed to higher nutrient levels especially nitrogen that was availed for maize growth. Combination of organic and inorganic nutrient sources likely resulted into synergy and improved conservation and synchronization of nutrient release and crop demand, leading to increased fertilizer use efficiency and higher yields. The control and sole maize stover (75 kg N ha^{-1}) had the lowest yields across all the seasons. However, supplementation of maize stover with 15, 30 and 45 kg N ha^{-1} urea increased maize grain yields by 36, 50 and 93 % respectively. Economic evaluation should however be done to determine economic feasibility of the tested technologies before they are recommended to farmers for adoption.

Keywords: Soil fertility, striga, maize yields

Introduction

Striga parasistism of cereal crops is one of the major biological constraints to attaining food production self sufficiency in small scale farming systems in sub-Saharan Africa (Esilaba and Ransom, 1997). The build up of *Striga hermonthica* (Del) Benth. is associated with declining soil fertility resulting from continuous-intensive cropping patterns without adequate fertilizer inputs (Tittonell *et al*., 2005; Vanlauwe *et al*., 2008), a common phenomenon in densely populated farming systems of western Kenya (Vanlauwe *et al.*, 2006). There are about 23 species of striga in Africa, of which *Striga hermonthica* (Del.) Benth., commonly known as striga, is the most socio-economically important constraint in cereal cultivation in eastern Africa (Gethi *et al.*, 2005). Striga weeds are known to cause crop yield losses of between 20 and 100 % for maize (Kim *et al*., 2002; Midega *et al.*, 2017;Vanlauwe *et al*., 2008) and 20-50 % in sorghum (Lendzemo *et al*., 2005; Midega *et al.*, 2017) although 100 % yield loss is not uncommon. Striga infests about 217,000 hectatres (about 15 % of the arable land) in the Lake Victoria basin of Kenya (CEPA, 2004), causing annual crop losses estimated at $53 million (Woomer and Savala, 2009). This profound yield loss necessitates the identification of management systems that increase and maintain adequate levels of soil fertility while at the same time reducing the striga weed infestation. The management of striga in Kenya has been constrained by the abundant seed production and the soil seed bank of striga plants, longevity of the seed bank, mode of parasitism and lack of capacity, knowledge and resources by small-scale farmers to control the weed.

Several processes for the action of Nitrogen on Striga have been investigated by scientists. The potential of nitrogen (N) fertilizers to suppress striga has been demonstrated in western Kenya farming systems (Esilaba *et al*., 2000; Gacheru and Rao, 2001). Unfortunately, inorganic nutrient applications by most smallholder farmers is constrained by a limited capacity to apply sufficient quantities to improve soil N supply for the crops and suppress striga weeds. Alternatively, organic inputs such as crop residues and foliar biomass from trees and shrubs commonly found in the farm landscapes could be used as sources of nitrogen for crop production and striga weed control (Niang *et al*., 1996). However the sole use of organic sources of N for crop production is not a practical option, due to limited quantities available, their low N contents, and the high labour demand and opportunity costs for transportation, application and competitive uses such as fodder for livestock and firewood (Jama *et al.*, 2000).

There is therefore increased interest in devising efficient ways of combining organic inputs and commercial fertilizers in order to improve soil properties and increase overall farm productivity (Nziguheba *et al*., 2004; Vanlauwe *et al*., 2001). One of the approaches is the increased use of organic resources in combination with mineral fertilizers in an integrated nutrient management strategy (Vanlauwe *et al*., 2002). Although the beneficial effects of combined organic and inorganic sources on soil fertility, crop yields and maintenance of soil organic matter have repeatedly been shown in field trials (Nandwa, 2003; Vanlauwe *et al*., 2002) the appropriate rates of organic and inorganic sources in the combinations are still not well established (Vanlauwe *et al*., 2002). The following study hypothesized that soil striga incidence was associated with soil nitrogen availability, and that maize productivity was linked to striga incidence, soil N availability and their management. The objective of this study was therefore to assess the effect of applying organic residues solely or in combination with urea on striga infestation and maize yield under small-scale farming conditions in western Kenya.

Materials and Methods

Experimental site

This study was conducted at Nyabeda (N 0° 08', E 34° 24') in Siaya District of western Kenya. The area is classified as a midland with an altitude of approximately 1330 m above sea level (Jaetzold and Schimdt ,1983). The rainfall distribution pattern is bimodal, allowing two cropping seasons a year with the long rains starting from March and ending in July, and the short rains commencing from August and ending in November, with an annual mean of 1800 mm (Figure 1). Mean annual temperature ranges between 22^0C and 24^0C. The soils are clayey, reddish, deep and well drained and are classified as Ferralsols (Kandiudalfic Eutrudox), (Jaetzold and Schimdt, 1983).

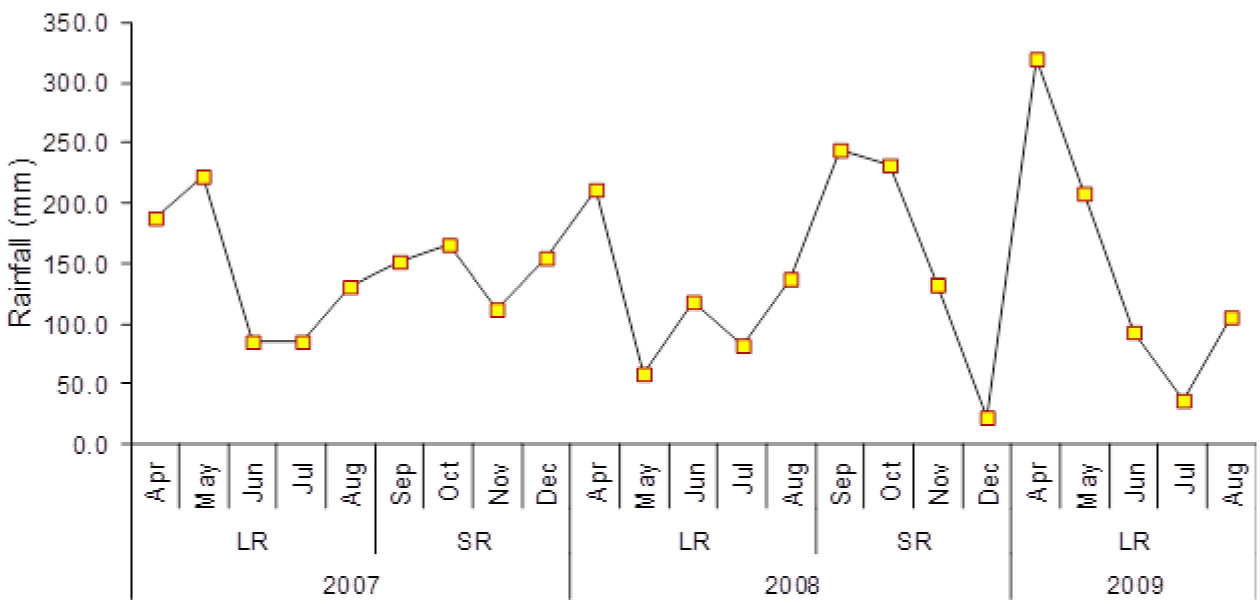

Figure 1. Rainfall at Nyabeda in 2007 to 2009

Soil sampling and analysis

Prior to the establishment of the trial, soil samples (0-15 cm) were collected from nine points in each plot and thoroughly mixed to form a composite sample. The composite sample was air dried, sieved to pass through a 2 mm sieve, then analysed for pH (1:2.5 water) according to

McLean (1965), organic carbon by Walkey and Black sulphuric acid-dichromate digestion followed by back titration with ferrous ammonium sulphate (Nelson and Sommers, 1982). The total N was determined by the Kjedhal method (Anderson and Ingram, 1993). The basic cations (Ca, Mg, K and Na) of the soil were extracted using ammonium acetate at pH 7 followed by determination of exchangeable Ca and Mg using atomic absorption spectrophotometry, and exchangeable K by flame photometry (Anderson and Ingram, 1993). The particle size distribution was determined by the Bouyoucos hydrometer method.

The soils chemical and physical properties sampled from the top 0-15 cm had the following characteristics; pH=4.9, total soil organic carbon 2.33 kg^{-1}, total soil N=0.23 g kg^{-1}, Olsen P=2.75 mg kg^{-1}, exchangeable Ca=7.95 $cmol_c$ kg^{-1}, exchangeable Mg=4.78 $cmol_c$ kg^{-1}, exchangeable potassium=0.05 $cmol_c$ kg^{-1}, exchangeable Na=0.40 $cmol_c$ kg^{-1},clay=23%, silt=14 % and sand =63 %. The soils in this area had critically low levels of P hence the need for application of 40 kg P ha^{-1}. Nitrogen levels were also low mainly attributed to continuous cultivation without adequate replenishment.

Experimental design, establishment and management

The experiment was laid out in a randomized complete block design (RCBD) with twelve treatments replicated four times. Treatments consisted of two organic sources of N (maize stover and residues of *Calliandra calothyrus* Messn.) and urea as the inorganic mineral source of N. Treatments were combined in the following ratios i.e 0:0, 100:0, 80:20, 60:40, 40:60, 20:80, and 0:100 so as to supply a total of 75 kg N ha^{-1} per treatment except the control i.e treatment 0:0 where no N inputs were applied (Table 2). Maize stover was obtained from neighbouring farms and Calliandra from an established demonstration plot within the area. In each season before their use, a sub sample of each organic input was anayzed for N content to determine the quantity to be applied. The plant residues were then weighed, chopped and incorporated into the soil at a depth of 15 cm during land preparation in all seasons. Phosphorus (P) and potassium (K) were uniformly applied to each plot of 6 m x 6 m at the rate of 40 kg P and 20 kg K ha^{-1} as triple super phosphate and muriate of potash respectively at the beginning of each season. One day after treatment application, maize variety WH502 was planted at a spacing of 75 cm between rows and 25 cm within rows. Two seeds were planted per hill and thinned to one seedling per hill two weeks after emergence (WAE) to give a total maize population of 53,333 plants ha^{-1}. Weeding was done at three and eight weeks after planting. In the appropriate treatments, urea was applied in splits with one third being applied at planting while the rest was applied as a topdress six weeks later.

Soil mineral N determination

Top soil (0-15 cm) samples from the different treatments were collected for mineral N (NH^+_4 and NO_3^-) determination at 4, 8, 10 and 12 weeks after organic residue and urea incorporation at each site. Samples were collected from nine points within each plot (0-15 cm) using augers and mixed to form composite samples. Samples were put into air-tight polythene bags and stored at 4 °C prior to extraction of mineral N. At the time of extraction, twenty five grams of soil sample was placed in an oven at 105 ^{0}C for 24 hours to determine soil moisture content at the time of sampling. For inorganic N (NH_4^+ and NO_3^-) determination, 20 g of field moist stored soil was extracted with 100 ml of 2 M KCl by shaking for 1 hr at 150 rotations min^{-1} thereafter filtered through pre-washed Whatman No.5 paper. Nitrate nitrogen (NO^-_3-N) was determined after reduction with cadmium (Dorich and Nelson, 1984). Ammonium (NH^+_4-N) in the extract was determined by the salicylate-hypochlorite colorimetric method (Anderson and Ingram, 1993). The sum of inorganic ammonium-N and inorganic nitrate-N constituted the total inorganic nitrogen.

Striga count and collection in the field

Data was collected on day of first *Striga* appearance and the maximum number of striga shoots that emerged in the field were counted in the six middle rows (4.5 m*6 m) at 2 week intervals starting from the sixth week after crop emergence, and converted to the number of striga plants m^{-2}.

Determination of total biomass

Maize grain and stover were harvested at physiological maturity from a net plot of 16 m^2 after leaving two rows of maize on each side of the plot and one metre from each to minimize the edge effect. Total ear and stover fresh weights were detemined. Ear and stover were sub sampled, weighed, and oven dried to constant weight at 65 °C. They were then separated into grains and cobs and the total dry matter of grains, cobs and the stover determined.

Statistical analysis

Data of striga infestation was transformed by natural logarithim to eliminate heterogeneity before analysis and normalize the data. Analysis of variance (ANOVA) on the data to determine the effects of treatments on striga incidence and maize grain yield were done using Genstat 16 for windows (Release 8.1). A regression analysis was carried out to determine the relationship between striga incidence and maize grain yield. The treatment differences of striga incidence were tested on the transformed values using the Least Significant Difference (LSD) test at 5 % probability.

Results

Soil mineral nitrogen

Soil mineral N showed significant differences between treatments ($p<0.01$) at 4 and 12 WAP. There was a general increase in soil N from 4 to 8 WAP followed by a decrease to 12 WAP (Figure 2). Maize stover applied at 30 kg N ha^{-1} combined with urea at 45 kg N ha^{-1} gave the highest mineral N of 56 and 59 kg N ha^{-1} at 4 and 8 WAP respectively. The same treatment increased soil mineral N above the control by 24 and 20 kg N ha^{-1} (on average, representing 74-

50%) at 4 and 8 WAP respectively. At 12 WAP Calliandra applied at 15 kg N ha^{-1} combined with urea at 60 Kg N ha^{-1} gave the highest mineral N (51.4 kg N ha^{-1}). The same treatment increased soil mineral N by 18 % compared to the control. Treatments with over 45 kg N ha^{-1} of maize stover had lower levels of mineral N at 4 and 12 WAP (Figure 2).

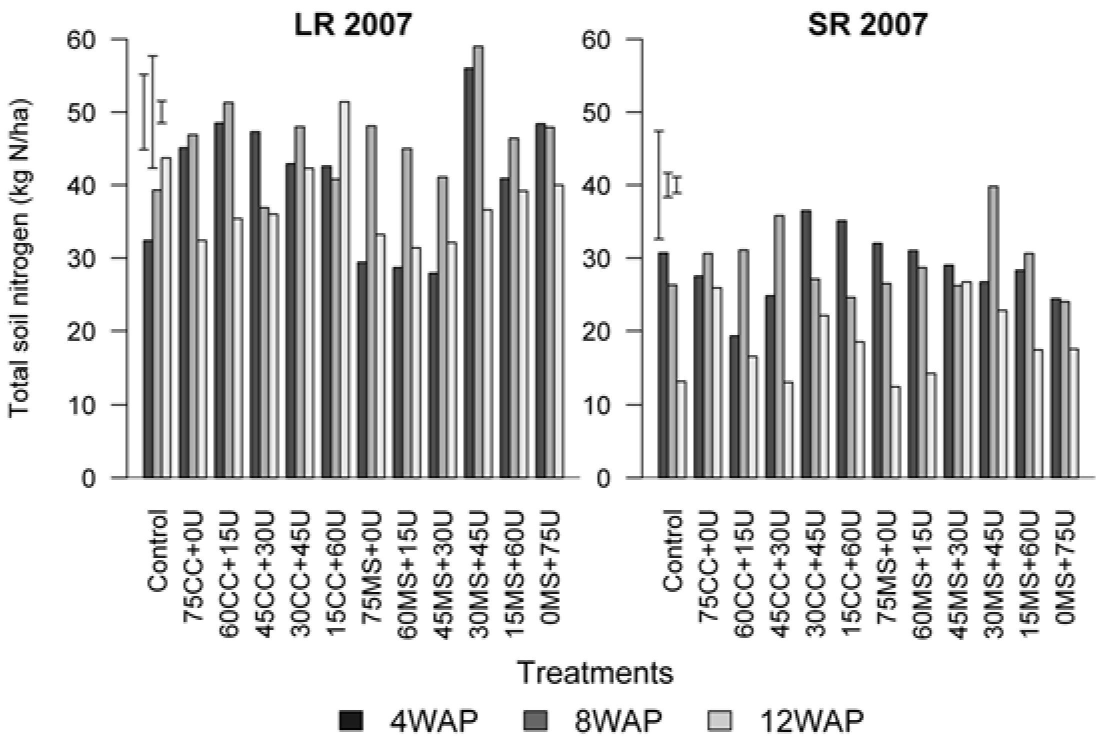

Figure 2. Total soil inorganic nitrogen at 0-15 cm soil depth sampled at different periods during 2007 at Nyabeda. The error bars are LSD (0.05) at 4WAP (first error bar), 8WAP (second error bar) and 12WAP (third error bar) within season

During the 2007 short rain season, significant treatment effects ($p<0.001$) were observed at 8 and 12 WAP respectively (Table 1). There was a general reduction in soil mineral N levels from 4 to 12 WAP. At 8 WAP, maize stover applied at 30 kg N ha^{-1} combined with urea at 45 kg N ha^{-1} and Calliandra applied at 45 kg N ha^{-1} combined with urea at 30 kg N ha^{-1} the highest mineral N of 39.8 and 35.8 kg N ha^{-1} respectively. The same treatments increased soil mineral N by 34 % and 36 % compared to the control. At 12 WAP, maize stover applied at 45 kg N ha^{-1} combined with urea at 30 kg N ha^{-1} and Calliandra applied at 75 kg N ha^{-1} had the highest mineral N of 26.7 and 25.9 kg N ha^{-1} respectively. The same treatments increased soil mineral N by 100% and 96% compared to the control. Maize stover applied at 60 and 75 kg N ha^{-1} depressed soil mineral N compared to the control. Soil mineral N levels were generally higher in the long rain season compared to the short rain season (Table 1).

Striga emergence

Seasonal trends in striga incidence over the period of study are summarized in Table 1. There were highly significant ($p<0.001$) differences between seasons. Except for 2007 SR, ($p<0.001$) effects of treatments on striga counts were not significant in all other seasons. The highest striga densities (115 plants m^{-2}) were observed in sole maize stover (75 kg N ha^{-1}) and maize stover applied at 60 kg N ha^{-1} combined with urea at 15 kg N ha^{-1}) (114 plants m^{-2}). The two treatments had significantly higher striga counts than all other treatments. Averaged over five seasons, striga density was higher in the control and in treatments receiving more than 80 % of N from maize stover (Table 1). In 2007 and 2008, striga emergence was higher during long rains than the short rain seasons.

Table 1. Effect of combined use organic residues and urea on *striga* counts (m^2) at Nyabeda, western Kenya (values in brackets are transformed values of striga incidence $\log_{10}(x+1)$

Treatments	**Seasons**				
	LR2007	**SR2007**	**LR2008**	**SR2008**	**LR2009**
			Plants m^{-2}		
Control	118 (2.07)	57 (1.76)	19 (1.28)	4 (0.60)	11 (1.04)
75CC+0U	146 (2.16)	45 (1.65)	13 (1.11)	4 (0.60)	9 (0.95)
60CC+15U	128 (2.11)	65 (1.81)	16 (1.20)	7 (0.85)	14 (1.15)
45CC+30U	117 (2.07)	29 (1.46)	10 (1.0)	4 (0.60)	12 (1.08)
30CC+45U	100 (2.0)	55 (1.74)	12 (1.08)	3 (0.48)	11 (1.04)
15CC+60U	105 (2.02)	38 (1.58)	13 (1.11)	4 (0.60)	8 (0.90)
75MS+0U	89 (1.95)	115 (2.06)	15 (1.18)	3 (0.48)	15 (1.18)
60MS+15U	141 (2.15)	114 (2.06)	16 (1.20)	7 (0.85)	15 (1.18)
45MS+30U	44 (1.64)	49 (1.69)	6 (0.78)	3 (0.48)	9 (0.95)
30MS+45U	68 (1.83)	37 (1.57)	9 (0.95)	5 (0.70)	8 (0.90)
15MS+60U	154 (2.19)	40 (1.60)	8 (0.90)	4 (0.60)	14 (1.15)
75U	126 (2.10)	49 (1.69)	11 (1.04)	4 (0.60)	9 (0.95)
Mean	111(1.96)a	58(1.68)b	13(1.01)c	4(0.67)d	11(1.01)c
P Level treat	0.44(0.18)	<0.001(0.003)	0.74(0.15)	0.59(0.76)	0.57(0.35)
LSD (0.05)	ns	38(0.29)	ns	ns	ns
CV	8.2	8.8	9.3	15.1	19.8
P season			<0.001		

LR=long rainy season, SR=short rainy season, CC=Calliandra, MS =maize stover, U=urea

Higher levels of soil N availability at 12 WAP were associated with lower levels of striga incidence. A linear regresion of soil N and striga incidence (Figure 3) showed that at lower N levels (10-20 kg N ha^{-1}), the striga levels during the LR 2007 season tended to exceed 100 plants per m^2, however, they declined to 40 plants m^2 when soil N levels approached 30 kg N ha^{-1}. The striga levels declined with increasing N levels in the SR 2007 season, though the incidence was lower in this season compared to the preceding season.

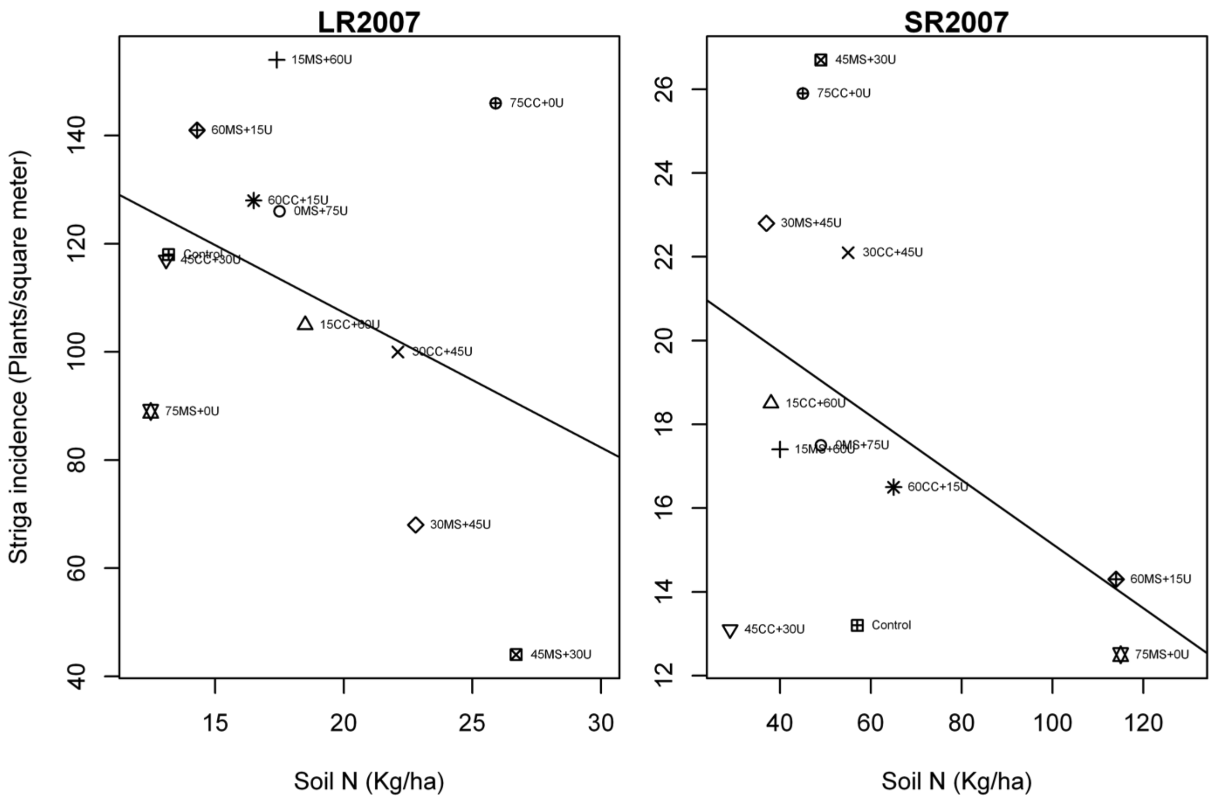

Figure 3. Relationship between soil-available N and striga incidence in western Kenya

Effect of organic and inorganic treatments on maize productivity

Total above ground biomass for different treatments across the five seasons are presented in (Table 2). Total biomass yields were significantly affected by treatments (p=0.05) in the long rainy seasons only. Overall, maize stover applied at 30 kg N ha^{-1} plus urea at 45 kg N ha^{-1} and Calliandra applied at 45 kg N ha^{-1} plus urea at 30 kg N ha^{-1} gave the highest mean yields of 8.3 and 7.9 t ha^{-1} respectively. The two treatments out yielded the control by 89 and 80 % respectively. The lowest yields were observed in sole maize stover and the control with 5.2 and 4.4 t ha^{-1} respectively. Above ground biomass yields during 2008 SR were the lowest among the five seasons of study.

Table 2. Effect of organic and inorganic treatments on maize biomass yield (2007-2009) at Nyabeda in western Kenya

Treatments	Seasons				
	2007 LR	**2007 SR**	**2008 LR**	**2008 SR**	**2009 LR**
	Above ground biomass (t ha^{-1})				
Control	3.9	6.0	2.4	3.3	6.6
75CC+0U	6.4	7.7	7.1	4.6	9.7
60CC+15U	4.2	9.3	5.0	3.3	8.2
45CC+30U	10.5	8.2	7.3	4.3	9.3
30CC+45U	8.3	9.3	5.9	4.4	9.0
15CC+60U	5.4	6.6	5.8	4.5	7.7
75MS+0U	3.4	8.0	2.8	3.7	8.0
60MS+15U	7.7	9.5	5.2	4.1	8.0
45MS+30U	6.3	8.2	5.2	4.9	10.4
30MS+45U	11.7	9.7	5.3	4.8	10.1
15MS+60U	7.3	6.9	6.7	4.2	7.5
75U	7.4	7.3	5.2	4.3	7.0
Mean	6.9	8.1	5.2	4.2	8.5
P level (Treatment)	0.002	NS	<0.001	NS	0.046
P level (Covariate)	0.049	0.030	<0.001	0.248	0.607
$LSD_{0.05}$	3.96	4.27	1.71	1.44	2.4
CV%	22.7	26.1	18.8	6.1	13.3

Maize grain yields were significantly affected by treatments ($p < 0.05$). Overall, maize stover applied at 30 kg N ha^{-1} plus urea (45 kg N ha^{-1}) and Calliandra applied at 45 kg N ha^{-1} plus urea (30 kg N ha^{-1}) gave the highest mean yields of 3.0 and 2.7 t ha^{-1} respectively (Table 3). The two treatments increased grain yields by 114 % and 92 % against the control and by 42 and 28 % against sole urea treatment. The control and sole maize stover consistently gave the lowest yields across all the seasons. However, supplementation of maize stover with 15, 30 and 45 kg N ha^{-1} urea increased maize grain yields by 36, 50 and 93 % respectively. Similar to the above biomass yields, maize grain yields were the lowest during 2008 SR and ranged between 0.8 t ha^{-1} (control) and 1.4 t ha^{-1} in Calliandra (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) (Table 3).

Table 3. Effect of organic and inorganic treatments on maize grain yield (2007-2009) at Nyabeda in western Kenya

Treatments	Seasons				
	2007 LR	**2007 SR**	**2008 LR**	**2008 SR**	**2009 LR**
	Grain yields (t ha^{-1})				
Control	1.2	1.4	0.9	0.8	2.6
75CC+0U	1.9	1.9	3.1	1.2	3.6
60CC+15U	1.5	2.5	2.3	1.1	3.5
45CC+30U	3.5	2.4	3.0	1.1	3.7
30CC+45U	2.6	3.0	2.4	1.4	3.7
15CC+60U	1.8	1.7	2.8	1.3	3.0
75MS+0U	1.0	2.3	1.0	1.2	3.1
60MS+15U	2.2	2.7	1.6	1.3	3.4
45MS+30U	2.0	2.2	2.3	1.3	4.1
30MS+45U	4.5	2.9	2.3	1.4	4.0
15MS+60U	2.6	1.9	3.2	1.4	2.7
75U	2.5	2.0	2.3	1.0	2.6
Mean	2.3	2.2	2.3	1.2	3.3
P level (Treatment)	0.013	NS	<0.001	NS	0.038
P level (Covariate)	0.016	0.013	0.002	0.109	0.638

'LR', 'SR', mean 'long rainy season', and 'short rainy season', respectively, CC=Calliandra, MS =maize stover, U=urea, NS= non-significant

Relationship between striga density and maize grain yield

Striga had negative effects on total biomass which in turn influenced maize grain yields. Maize yields generally decreased with increasing striga infestation, however, the negative linear relationship between maize yield and striga population was only significant in the first three seasons of 2007 LR, 2007 SR and 2008 LR (Figure 2). Regressions of maize parameters on striga revealed stronger negative effects of striga on total biomass and grain yield under stover applications compared to Calliandra in 2008 LR season.

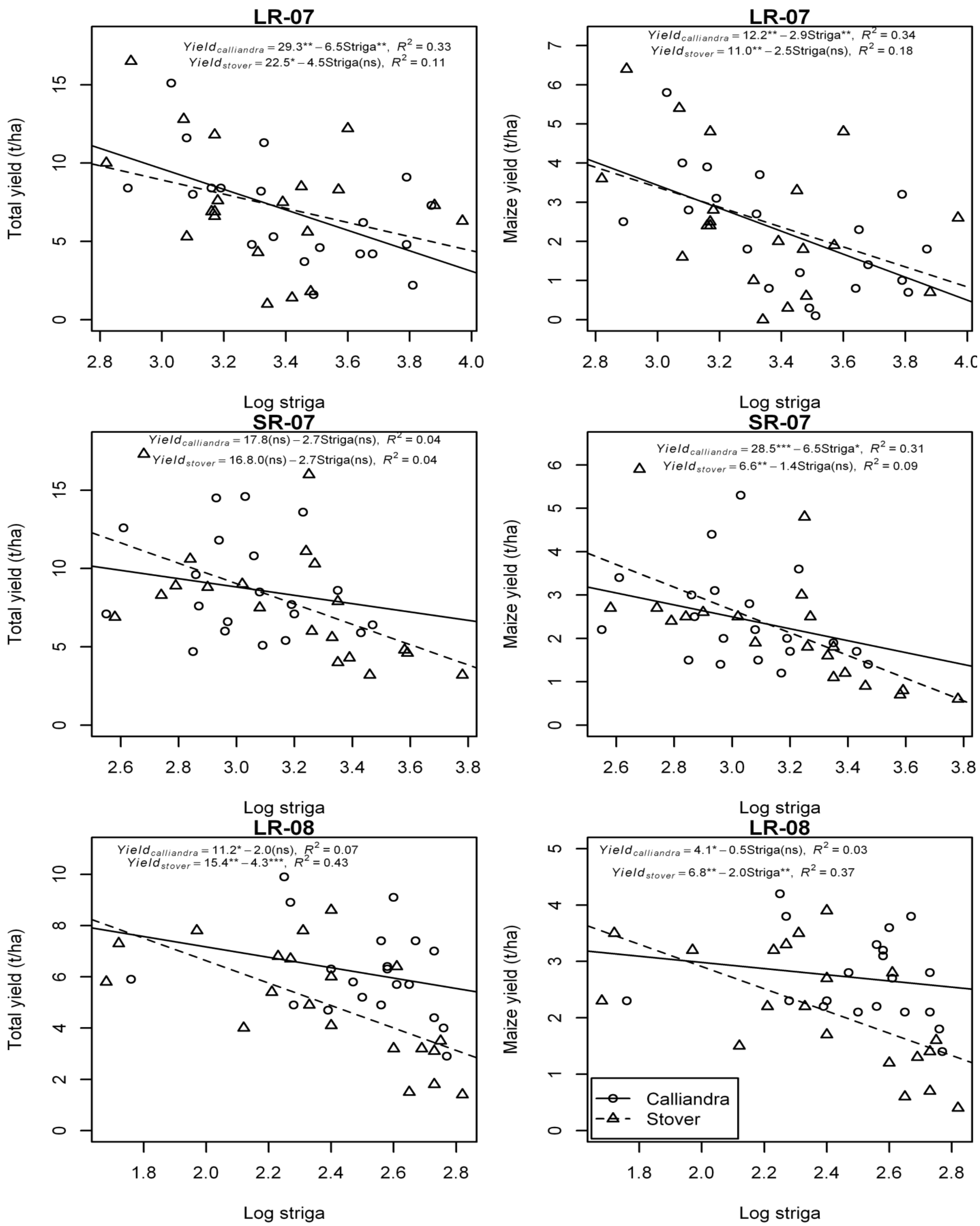

Figure 4. Relationship between striga density, total maize biomass and maize grain yield. 'LR', 'SR', means 'long rainy season', and 'short rainy season', respectively. ns = not significant

Discussion

Soil mineral N dynamics

The different patterns observed in the amounts of soil inorganic N at the different sampling times was attributed to differences in rainfall patterns, decomposition rates and N release patterns of the two plant residues (Calliandra and maize stover) used in the study and the proportion in which two were combined with urea. The increase in mineral N from 4-8 WAP could be attributed to N release through mineralization and N added as urea at 6 WAP as topdressing. Reduction of soil inorganic N from 8 WAP to 12 WAP was mainly attributed to decrease in mineralization, N uptake by plants coupled with N denitrification, immobilization and leaching (Greenland, 1958); leaching can result in appreciable loss of topsoil NO^-_3 (Poss and Saragoni, 1992). The loss through leaching was more likely due to high amounts of rainfall received during this period (Figure 1). Such phenomenon was reported by Thornton *et al*. (1995) who estimated 40 to 50 % of the mineralized N being lost under high rainfall environments through leaching and Myers *et al*. (1997) who noted that leaching of mineral N in the soil increased as the rainfall amount increased. However reduction in soil inorganic N noted in 2007 short rain season is most likely attributed to low and unreliable rainfall that was received in that season (Figure 1; Figure 3). Soil moisture plays an important role in decomposition, N release and movement in the soil. The difference between the amounts of inorganic N between the two seasons may be related to the previous seasons rainfall and crop yield. The consistently higher amounts of mineral N under maize stover combined with urea in the ratio of 40:60 at 4 to 8 WAP could be attributed to the higher proportion of urea applied at planting. This early and consistent supply of N is important for crop development (Serrem, 2006). This may therefore explain the higher yields realized under these treatments. Low levels of mineral N in plots with high levels maize stover could be attributed to slower rates of decomposition and N release. Low quality organic materials such as maize stover with high C/N ratio (70) take long to decompose and release N for plant uptake (Gachengo *et al.,* 1999). According to Palm *et al*. (2001), addition of organic materials with a total N content of 1.5 % can trigger N immobilization in soil. The maize stover that was applied in this study had a total N content of 0.65 %, which was below the critical level suggested by Palm *et al*. (2001). The benefits of such residues to the crop may be through the long term buildup of N rather than the direct use of N from the decomposing residues (Palm, 1995).

Effect of soil amendments on striga emergence

The consistently lower striga infestation under maize stover applied at (30 kg N ha^{-1}) plus urea (45 kg N ha^{-1}) and Calliandra (45 kg N ha^{-1}) plus urea (30 kg N ha^{-1}) could be attributed to higher nutrient levels more so nitrogen (mineral N) that was provided by these treatments. A number of studies have reported a decrease in striga infestation and an increase in crop yields with application of high levels of N (Esilaba *et al*., 2000; Gacheru and Rao, 2001; Kiwia *et al*., 2009). It is however important to note that mechanisms responsible for the reduced striga infestation and damage to host plants due to nitrogen are not fully understood (Van Mourik, 2007). Many scientists however, attribute the effect of nitrogen to delayed germination, reduced radicle elongation, reduced stimulant production and reduction of seeds response to the stimulants (Hassan *et al*., 2009). The higher striga densities in the control and sole maize stover treatments could be attributed to low N levels mainly as a result of immobilization. Host plants produced in environments that are low in N produce higher levels of the striga stimulant leading to higher striga germination (Cechin and Press, 1993).

Higher striga incidences in the long rainy seasons compared to shorter rain seasons could be attributed to better conditions for striga seed conditioning (i.e physiological preparation) of striga seeds for germination. Rainfall distribution was more uniform during the long rains and this resulted in more consistent conditioning while during the short rains, there was always a dry period in between September and main rains for crop development in November. Alternating moist and dry conditions could easily make conditioning seeds become dormant again (Odhiambo, 1998).

Effect of treatments on maize productivity

The higher maize yields recorded in treatments where maize stover was applied at 30 kg N ha^{-1} plus urea 45 kg N ha^{-1} or Calliandra (45 kg N ha^{-1} plus urea 30 kg N ha^{-1} was attributed to higher amounts of nutrients especially nitrogen that was availed by these inputs. This is an indication that integrated use of organic and inorganic nutrient sources of N is advantageous over the use of inorganic fertilizer alone. Integration of inorganic and organic nutrient inputs could therefore be considered as a better option in increasing fertilizer use efficiency and providing a more balanced supply of nutrients. Several earlier studies have demonstrated that the use of organics could enhance efficiency of chemical fertilizers (Dudal, 2002; Mucheru *et al*., 2006; Mugwe, 2007). Vanlauwe *et al*. (2002) reported that combination of organic and inorganic nutrient sources results into synergy and improved conservation and synchronization of nutrient release and crop demand, leading to increased fertilizer use efficiency and higher yields.

The low yields obtained when maize stover was applied to supply N at higher rates is attributed to immobilization of N by the maize stover. The maize stover had a C:N ratio of 65 which is way above the minimum threshold of < 20 that is required for mineralization to occur. In addition, the stover was high in lignin and polyphenol content which are likely to have exacerbated the immobilization (Delve *et al*., 2001) and the maize growing in these treatments therefore suffered deficiency. Combining the maize stover with urea at high rates reduced the C:N ratio to lower than 20 and affected mineralization which overcame the N deficiency. In addition, the low yields in sole maize stover treatments could also be attributed to high levels of striga infestation under these treatments (Table 1). Reduction in crop yields realized from striga infestation result from a series of physiological changes in the host plants following striga parasitism. These include weakening of the host, wounding of its outer root tissues and absorption of moisture, photosynthates and minerals (Tenebe and Kamara, 2002). Apart from parasitism, striga impairs photosynthetic efficiency (Stewart *et al*., 1991) and exerts toxic or phytotoxic effects (Gurney *et al*., 2006).

Calliandra on the other hand had a high N content (3%) and low C:N ratio (15:1) hence would be expected to mineralize even without the addition of a readily soluble source of N such as urea if other factors were constant. However, due to its high polyphenol (14%) and lignin contents (25%) the rate of mineralization is likely to have been slowed down when applied alone without urea. According to Palm *et al*. (2001) organic materials with a polyphenol content of > 4 % and lignin content of > 16 % will immobilize N and have therefore to be supplemented with inorganic N fertilizers. Hence addition of urea even in modest amounts to Calliandra was enough to overcome the deleterious effects of these compounds and enabled mineralization to occur at faster rates to provide enough N for the maize and therefore the high yields in the Calliandra/urea combinations. The generally good response to urea when sole-applied (75 kg N ha^{-1}) was expected since this site was N deficient and urea provided N in readily available form.

However, the slight superiority of the treatments where urea was integrated with Calliandra is attributed to synergistic effects often observed when appropriate organic and inorganic sources of nutrients are combined. For example, organic materials confer other advantages e.g. moisture retention, provision of micronutrients and alleviation of mineral toxicities (Opala *et al*., 2007).

The relatively low maize grain yields in 2007 and 2008 short rainy seasons could be attributed to the low and unevenly distributed precipitation that was received in the two seasons, respectively. The precipitation received during the 2007 SR (Sep–Nov) totaled 355 mm and most of it (86 %) was recorded in the first eight weeks of the season (Figure 1). During the 2008 SR season a total of 800 mm was recorded with 70 % of the rain received within the first eight weeks of the season and low during the later part of the season coinciding with maize reproductive phase. The low and poorly distributed rainfall could have reduced the availability of nutrients such as N to the maize plants because soil moisture content influences N mineralization and subsequent and N uptake and hence maize growth (Soon *et al*., 2001).

Conclusion and recommendation

Maize stover (30 kg N ha^{-1}) applied in combination with urea (45 kg N ha^{-1}) or Calliandra (45 kg N ha^{-1}) applied with urea (30 kg N ha^{-1}), gave the highest grain yields and had the lowest striga incidences. Combining organic and inorganic N resulted in synergistic effects, particularly in drier moisture stressed growing seasons. This synergy and other extra benefits of organic materials should be exploited by smallholder poor farmers. Economic evaluation should however be done to determine economic feasibility of the tested technologies before they are recommended to farmers for adoption. Maize stover tended to encourage striga infestation and depress yields when applied in large quantities likely due to immobilization of nitrogen. This is the likely reason why farmers prefer to burn it. However, due to its importance in maintaining soil organic matter, it should be retained in the field and urea applied at higher rates to overcome N immobilization where it is economically feasible.

Acknowledgements

We are grateful to Evan Tambwa for managing field experiments. Financial support for this study was provided by Kenya Forestry Research Institute (KEFRI).

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Influence of Agricultural Lime Application with Inorganic Fertilizers on Soil pH and Maize Yields in Western Kenya

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Abstract

Stakeholders in agriculture are in agreement that improved farm productivity is the main entry point for breaking rural poverty and food insecurity in Sub-Saharan Africa (SSA). Approximately 90 % of inhabitants of western Kenya an equivalent to one eighth of the Kenyan population, are smallholder farmers living on less than US$ 1 a day and facing 3-5 hunger months in a year. Soil related challenges especially low soil fertility, in particular deficiencies in phosphorus and nitrogen compounded by medium to high soil acidity have led to low crop production from the potential of 4-6 tons ha^{-1} to less than 1 ton ha^{-1}. Majority of western Kenya smallholder farmers know the benefits of using fertilizers, but fertilizers are not affordable to most of them. As opposed to fertilizers, very few farmers understand the consequences of acidic soils and their management for enhanced crop response to key nutrients as the concept of soil pH is largely unknown among farmers. Due to these challenges, crop yields are low, hunger levels are high and poverty indices continue to increase in the region. This situation could be reversed if the productivity of smallholder farms is improved. However, the most agronomic advice by Agricultural Extension workers is based on guidelines which advocate for commercial fertilizer without other soil amendments like liming. A study that aimed at demonstrating the proper use of lime and fertilizer to increase maize crop yield was conducted for four consecutive seasons (2009 short rains to 2011 long rains season) in Kakamega and Siaya counties to evaluate the effects of lime combined with fertilizers. The design of the study was a randomized complete block (RCBD) with four treatments; Lime, Lime + DAP, Lime + Mavuno and control with maize as a test crop. Results showed improvement of soil pH from 4.91 to 5.23 0.32 difference, available phosphorus from 1.88 to 7.88 ppm, maize yield frm 0.9 to 4.99 t ha^{-1} and demand for fertilizer and lime by farmers from agro-dealers increased from one in 2009 to eight by the end of 2011. Although the project only demonstrated lime use on maize crop, lessons learnt from increased maize yield motivated farmers to apply lime on other crops such as sugarcane, banana, sweet potatoes and bean fields. It was observed that there was significant difference between control and two other treatments except lime ($p < 0.5$). It was also noted that, overall farmers rating of technologies based on maize yields at harvest was Mavuno + lime first followed by lime + DAP then lime alone and control last. The study therefore, recommends that liming technology with Mavuno fertilizer be adopted in similar acidic soils in western Kenya in order to ameliorate soil

acidity, improve food security and enhance economic growth and livelihoods of smallholder farmers. The study also recommends that more research be conducted to come out with optimum rates, times and methods of lime application with nutrients inputs.

Introduction

Stakeholders in agriculture are in agreement that improved farm productivity is the main entry point for breaking rural poverty and food insecurity in Sub-Saharan Africa (SSA) (Sachs, 2005; Denning *et al*., 2009). Approximately 90 % of inhabitants of western Kenya, who make up one eighth of the Kenya's population, are smallholder farmers living on less than US$ 1 a day and facing 3-5 months of hunger in a year. Soil related challenges have often reduced crop production from the potential 4-6 tons ha^{-1} to approximately 1 ton ha^{-1} (Sileshi *et al*., 2010). This productivity gap is linked to low soil fertility, in particular, phosphorus and nitrogen deficiencies, compounded by medium to high soil acidity in some locations (Okalebo *et al*., 2005).

Although majority of western Kenya smallholder farmers know the benefits of using fertilizers, the cost is prohibitive to most of them. However, very few farmers understand the consequences of acidic soils and their management for enhanced crop response to key nutrients (Kanyanjua *et al*., 2004). Due to these challenges, crop yields are low, hunger levels are high and poverty indices continue to increase in the region. This situation could be reversed if the productivity of smallholder farms is improved. Western Kenya region has two cropping seasons in a year and can, be productive if farmers are supported with the right agronomic information, inputs and markets.

This paper presents details of how Kenya Agricultural and Livestock Research Organization (KALRO) through the support of Alliance for Green Revolution in Africa (AGRA) developed innovative interventions that have contributed to widespread recognition and use of fertilizer and lime in Kakamega and Siaya counties of western Kenya. The study inspired farmers, private companies and commercial banks enthusiasm, enabling them to work together in a sustainable private public partnership (PPP) model. The implications of such interventions on maize crop yield and household wealth as well as challenges and required policy interventions are also presented.

Material and Methods

Site characteristics

The study areas were: Malava (UM1) in Kakamega County and Ugenya (LM2) in Siaya County which are part of Lake Victoria basin. The sites receive an average annual rainfall of between 1,200 and 1800 mm (Table 1), distributed into two distinct seasons, the long rains from mid-March to July and short rains from September to December. The Malava soils are more acidic than Ugenya soils, but generally soil acidity and low soil fertility are important challenges to crop yield improvement in the two Sub Counties (Okalebo *et al*., 2005). Maize is the most dominant food crop, planted in over 80 % of land devoted to food crops. In Malava, sugarcane is widely grown as a cash crop. Other crops such as sweet potatoes, bananas, soybeans, climbing beans and groundnuts are also grown, but the land area and time devoted to their production is limited.

Table 1. General soil and climatological characteristics of Malava and Ugenya Sub-Counties, in Kenya

Sub County	pH $_{H2O}$	P (ppm)	Organic-C (%)	Soil textural class	Annual average rainfall (mm)
Malava	4.0-5.8	1.7-12	0.9-2.0	Sandy loam	1300-1750
Ugenya	5.5-6.4	1.4-9.5	0.7-1.0	Sandy clay loam	1200-1400

Approach

The study aimed at demonstrating proper use of lime with fertilizer to increase maize crop yield using a value chain approach over a 3-year period from 2009-2011. The study started with 90 mother demonstration sites, followed by promotion of the best bet technologies for widespread uptake through an input, information, finance and market farmer support system.

Treatments in the mother demonstration sites included: lime 26 % CaO (2.0 t ha^{-1}), Diamonium phosphate 18 % N and 46 % P (20 kg P ha^{-1}), Mavuno[1] (20 kg P ha^{-1}), lime (2.0 t ha^{-1}) + DAP (20 kg P ha^{-1}) and, lime (2.0 t ha^{-1}) + Mavuno (20 kg P ha^{-1}), and the conventional farmers practice (FP) as a control. For all lime plots, lime was applied before planting slightly prior to the short rains of 2009. Both Mavuno and DAP were applied at planting in each of the three seasons. The Mavuno plots were top dressed with Mavuno top-dress fertilizer, while DAP plots were top dressed with CAN as per the fertilizer recommendations. Data on maize yield and soil characteristics were collected and analyzed using analysis of variance (ANOVA).

Farmers and other stakeholders were exposed to technology performances through demonstrations and a series of field days that allowed all participants to evaluate the performance of each technology during various stages of crop growth. The field days brought together stakeholders that included farmer groups, individual farmers, financial institutions, agro-dealers, seed companies, fertilizer and lime manufacturers, scientists, extension agents and development partners; with an intention of creating a good working relationship between stakeholders in the entire production value chain. To reach those who did not attend field days, similar information was packaged and disseminated through radio stations, Television and brochures. To encourage sustainable and widespread adoption beyond the project period, fertilizer and lime packs were provided freely during the short rains of 2010 to 5,000 farmers to try on approximately half an acre. Further, these farmers were trained on proper use of fertilizer and lime application and were

[1]Mavuno -(10% N; 26% P; 10% K; 4% Sulphur; 8% calcium and 4% magnesium)

influenced to train other interested farmers. In subsequent seasons, farmers were encouraged to buy fertilizer and lime at study subsidized rate from agro-dealers who had been financially supported by the study to stock lime, fertilizer and improved seeds to ensure input availability to the farmers. Through observation of crop performance and interactions with other stakeholders, the lime, seed and fertilizer companies and agro-dealers were convinced about existence of profitable business opportunity and started doing business with farmers. KALRO and AGRA also undertook monitoring and evaluation missions.

Results and Discussion

Fertilizer and lime use improved

Fertilizer and lime demand increased, leading to development of profitable fertilizer and lime business opportunities for agro-dealers. This led to an increase in the number of lime and fertilizer stocking agro-dealers from one in 2008 to eight by the end of 2011 (Table 2). The few lime stocking agro-dealers prior to 2009 were a result of low demand, but that changed as farmers awareness on importance of liming acid soils, and capacity to apply it was improved.

On-farm fertilizer use in the study sites increased from a 2008/2009 baseline of 584 tons per year to 3,078 tons per year (Table 2) by the end of 2011. While the demand for lime in study sites was only 74 tons per year at initiation of the project, three years into the project, lime demand increased to 28,500 tons per year. Consequently, the area under lime increased from 75 ha to 15,476 ha, , within that same period.

Although the study demonstrated lime use on maize crop, lessons learnt from the demonstration motivated farmers to try lime on other crops such as sugarcane, bananas, sweet potatoes and bean fields and the results were positive. They reported a 3 folds increase from 4 to 12 tons ha^{-1} in sugarcane yields when lime was incorporated into production of sugarcane. From zero use of lime on sugarcane in 2009, by the end of 2011, approximately 2,800 ha of sugarcane fields were limed at planting. Upon noticing the positive impact of fertilizer-lime combination, West Kenya Butali Sugar Company started widespread promotion of the use of lime in sugarcane production with a target of reaching over 30,000 contracted sugarcane farmers. In the same areas, approximately 6,500 ha of acidic maize fields were put under lime by the end of 2011. In addition to lime and fertilizer, use of improved maize seeds increased by 300 %.

Through a smart subsidy system and negotiations between study implementers with fertilizer and lime manufacturers, the price of lime and fertilizer decreased by up to 20 %. In addition, through AGRA, the financier of the study Equity Bank, acted as a credit guarantee, and reduced the cost of credit advanced to farmers from 19 % to 10 %, through a program that is commonly referred to as Kilimo Biashara - agriculture for business. In addition, six village saving groups were formed during the period of the study to enable farmers to pool resources to enable them buy fertilizer and lime in bulk, and therefore benefit from economies of scale, advance credit to members and to vet credit-worthy members for bank credits. As a result, a significant number of farmers from within the study sites and beyond have been able to access credits and purchase fertilizer, lime and improved seeds for use in their farms and the enthusiasm of all the stakeholders has continued to grow.

Table 2.Overall number of agro- dealers, uptake of improved seeds, fertilizers and lime and land area under fertilizer and lime in study sites over the study period

Variable	**2008**	**2010**	**2012**	**% Change 2008-2012**
Number of agro- dealers	1	2	8	500
Improved seeds access by farmers (tons)	105	708	1,706	300
Fertilizer access by farmers (tons)	584	1,356	3,078	400
Lime access by farmers (tons)	74	6,000	28,500	>1000
Areas under fertilizer (ha)	4, 672	8,580	26,664	470
Area under lime (ha)	75	3,768	15,476	>1000

Soils health and crop yield improved

Liming increased soil pH by approximately 0.5 in each site (Figure 1). Inclusion of lime, as a soil amendment, increased maize crop yield by between 200 and 300 kg ha^{-1}. Although such yield response may appear small, farmers were nevertheless excited by this increase, especially in plots that previously yielded almost nothing. Part of this excitement was also associated with observed *Striga hermonthica* reduction in limed plots. Striga infestation causes maize yield losses upto 100 % in highly-infested fields in the region (Vanlauwe *et al.*, 2008). In the case of this study, the striga counts were lower by approximately 57 % in limed plots relative to unlimed control plots.

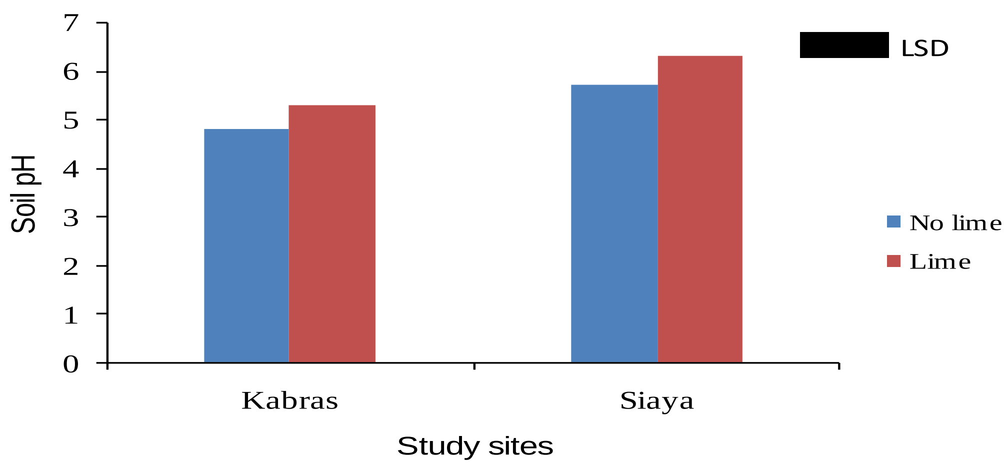

Figure 1. Effect of lime on soil pH across 90 demonstration farms in Malava in Kakamega and Ugenya in Siaya Counties

A combination of lime and fertilizer increased maize yield by more than 300 % relative to the farmers' practice in the demonstration sites (Figure 2). This indicates that by use of a combination of fertilizer and lime, significant improvement can be made on maize crop yield and food security situation in western Kenya (Figure 3).

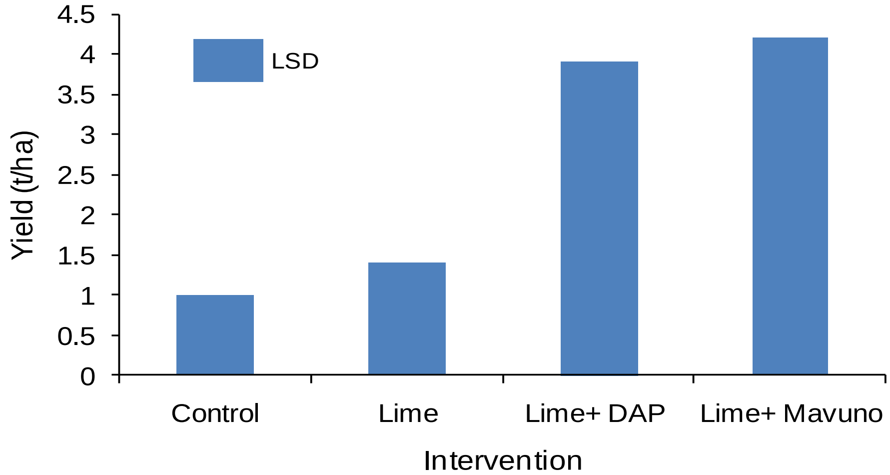

Figure 2. Effect of fertilizer and lime on maize crop in 2009/2011 period in Malava and Ugenya Sub-Counties. The data represent means from 90 demonstration farms for the period between 2009 and 2011.

Implications of improved production on household food security and incomes

Most of the farmers selected fertilizer + lime as the best bet technologies to adopt on their farms. Seasonal yields for each of the two sites are presented in Table 2. Application of a combination of lime and fertilizer increased annual on-farm maize yield from 1.3 tons ha^{-1} to 6.1 tons ha^{-1} in Kakamega and from 1.8 tons ha^{-1} to 6.4 tons ha^{-1} in Siaya (Table 2). The maize yield increase attributable to lime and fertilizer was more than 300 %. Additionally, putting into consideration that the average household farm size in western Kenya is 0.5 ha, then by application of recommended rates of fertilizer and lime, a household would produce an annual average maize yield of 6.1 tons per year in Kakamega and 6.4 tons per year in Siaya.

Table 2. Seasonal and annual on farm maize yield in fertilizer + lime and farmer practice plots for the 2010/2011 period in Malava and Ugenya Sub Counties

	Kakamega	**Siaya**	**Kakamega**	**Siaya**
	Fertilizer+ Lime (tons ha^{-1})		**Farmer practice (tons ha^{-1})**	
Long rains	3.3	3.4	0.8	1.2
Short rains	2.8	3.0	0.5	0.6
Annual total	6.1	6.4	1.3	1.8

A household of 5.5 persons feed on approximately 1 ton of food per year (Denning *et al.*, 2009). By adoption of recommended fertilizer rate + lime, an average western Kenya household of 6 persons (GOK, 2010) could therefore produce sufficient maize for consumption (1 ton per year), and remain with a surplus of 2.1 tons tons peryear valued at approximately US$ 795 for sale. Financial returns to fertilizer + lime over the farmers practice with maize crop stood at US$ 815 /ha/year and the fertilizer + lime application was financially attractive, with a benefit-cost ratio of 2.2. By definition, an intervention is financially attractive when its benefit-cost ratio is more than 2, implying returns of US$ 2 per every US$ 1 that is invested (Kaizzi *et al*., 2011).

Maize planted with no inputs in Malava

Maize planted with fertilizer and lime

Beans planted with fertilizer and lime in Ugenya

Agro-dealer shop in Kabras, Malava Sub-County western Kenya

Figure 3. Maize and beans planted with and without lime and fertilizer and agro dealer shop in Malava

Implications for a food secure western Kenya region

Out of the planned 30,000 farmers to be reached initially, the study managed to reach 20,000 farmers with information on fertilizer and lime at a cost of US$ 500,000 within a three year period. This implies that approximately US$ 25 was used to reach each farmer. With a smallholder farmer population of 5 million in the area, approximately US$ 125 million would be required to reach the entire western Kenya farming population. Further calculations indicate that on average, it costed approximately US$ 87 to produce 1 ton of maize with fertilizer and lime. This little investments in fertilizer and lime increased maize yields several folds in this area that is endowed with good rainfall and growing conditions for crops, but the area is unfortunately food insecure.

Policy implications

Policy interventions are necessary to achieve widespread adoption of fertilizer and lime use in order to increase crop yield, reduce food insecurity and boost income of rural poor in western Kenya. With good agricultural input policies, the resulting increased surplus produce from western Kenya could also improve food availability in the neighboring lesser productive arid and semi-arid regions (ASALS), which are characterized by frequent droughts and famines.

The effectiveness of extension services is limited by low extension worker-farmer ratio of 1:4000, and inadequate budgetary allocation to the line ministries in addition to poor training. Irrespective of technology development by research teams, farmers are often unaware of such technologies. For example, the technologies that were promoted by this study may have existed before, but their adoption was low partly due to ineffective dissemination. There is therefore a need for a targeted agricultural policy to address; capacity issues of extension workers, increase number of extension workers, and increase budgetary allocation to line ministries.

The crop yield increased significantly from 1.3 tons ha^{-1} to 6.1 tons ha^{-1} in Kakamega and from 1.8 tons ha^{-1} to 6.4 tons ha^{-1} in Siaya (as a result of lime with fertilizer use. However, the recommended 50 kg P ha^{-1} costs between US$ 90 and US$ 105 ha^{-1}. Over 80 % of smallholder western Kenya farmers cannot afford sufficient fertilizer at this cost, in addition to lime and improved seeds (Ariga *et al*., 2008). There is an urgent need for a policy that improves farmers' capacity to purchase farm inputs either through "smart subsidies'' or reduction of cost of credits for farmers. Sachs *et al.,* (2004) noted that a temporary investment by governments, state corporations, donors and private sectors for a few years can enable poor populations to permanently escape the poverty traps.

The market for surplus produce is often either lacking or the farm gate prices are too low especially immediately after crop harvest when farmers need to sell the produce to raise money to buy inputs for the next season. There is a need for policies that can buffer farmers against negative price variability. Such a policy would make agriculture a profitable business and possibly reduce rural-urban migration of agricultural labor. Rural urban migration is currently blamed on the lack of adequate labor for agricultural activities.

Lessons learnt

A number of lessons were learnt from this study. These were: i). Improving crop productivity on acidic soils of western Kenya and other areas with similar conditions requires a combination of inputs, including lime, inorganic materials, coupled with improved crop varieties and appropriate agronomic practices, ii) The inorganic fertilizers and lime are important for optimal agricultural production in acidic prone soils as lime corrects soil acidity while inorganic fertilizer add nutrients, iii) The combination of various dissemination techniques and approaches such as participatory on-farm demonstrations, farmer field days, farmer exchange visits, and linking farmers with agro dealers have enabled a large number of farmers to learn and adopt soil liming, iv) The interaction of multiple stakeholders is crucial for enhancing information access, input availability, input financing and marketing in order to encourage uptake and adoption of liming technology.

Conclusion

Application of lime alone will increase soil pH, but will not significantly improve maize yield without addition of organic fertilizers. In this study, application of lime alone did not significantly increase maize yield, but the effect was close to farmers' practice. This finding concurs with early studies elsewhere in Africa**.** Data obtained from liming experiments in other parts of Africa have shown that addition of lime alone is insufficient to rehabilitate poor or depleted soils. Further, increased use of inorganic fertilizers alone can exacerbate soil acidity problem. As a result, the combination of lime and inorganic fertilizers has been observed to be the most efficient technique of addressing the problem of soil acidity and enhancing soil fertility. This can further be supported by the use of improved germplasm that is tolerant to acid soils. Thus, establishment of a clear system of support and policy is likely to address a significant proportion of western Kenya households from food insecurity and poverty trap. It is possible to build a private-public partnership that addresses agriculture as a comprehensive system, thereby creating gains for all the stakeholders.

Recommendation

It is recommended that before applying lime, soil sampling, analysis, interpretation and recommendation should be done. Also site morphological and characterization be carried out to better understand the soil health of the area. Findings of this study recommends that smallholder farmers in acid soils of western Kenya and any other areas of the country that have similar soil acidity problems, adopt combined use of lime with inorganic fertilizers and improved maize seed for the economic growth and profitability from the increased maize yield in targeted acid soils in western Kenya.

Acknowledgement

We are grateful to Alliance for Green Revolution in Africa (AGRA) for funding this study. We also acknowledge with special thanks Remigius Ochebo for his commitment and dedication as he led the field data collection team, all technicians in the plant and soil laboratory at KALRO Kakamega that assisted in analyzing the data, farmers of Got Nanga in Ugenya Sub County Siaya County and Kabras in Malava Sub County Kakamega County for their willingness to participate in this study. The Director General KALRO, Vice Chancellors of MMUST and UoE, Centre Director, KALRO Kakamega are also thanked for facilitating the successful implementation of the study. We also thank the former Director; Farmer Solutions Programme of

Alliance for Green Revolution in Africa (AGRA) Dr. Bashir Jama for his timely guidance and advice.

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Meeting the Phytosanitary Requirements in Tree Germplasm Exchange in East Africa: Awareness on Importance, Challenges and Opportunities of Tree Seed Health among Stakeholders

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Abstract

Globally, over 90% of tree species are propagated through seed and raised as seedlings. Other propagation materials include cuttings, wildings, grafts, tissue culture and air-layering. Since seed is the main source of planting material and medium of tree germplasm exchange, it is also the major source of disease and pest introduction in new localities worldwide. Seed microflora usually comprises of fungi, bacteria and to lesser extent viruses, and can be external or internally seed borne. Some tree nurseries have reported over 80% losses to seed related diseases.

There has been an increase in tree diseases and pest incidences affecting the main plantation and agroforestry tree species in Kenya. Most pathogens are transmitted through seeds and cuttings while endophytes are transmitted through healthy looking host materials. For example, four major diseases and pests of eucalypts are reported to be on the increase within Africa. Their invasions are closely related to the continuous importation of *Eucalyptus* clones which have been traced to South Africa, Latin America and Australia. The future of local landraces of eucalypts are therefore unpredictable unless suitable biocontrol agents are introduced soon. In similar circumstances, the *Dothistroma* needle blight has almost stopped the growth of *Pinus radiata* in East Africa. The latent pathogen group; Botrosphaeriaceae is reported to be spreading fast on the popular *Grevillea robusta* and other tree species in Kenya.

Tree germplasm production and exchange unlike the food crops faces phytosanitary challenges that include inadequate sources of high genetic quality, low seed production due to unpredictable flowering patterns, uncontrolled movement of live germplasm and forest products, inadequate enforcement of the relevant legislations on tree seed trade, inadequate formal quarantine standards especially for indigenous tree seeds and inability to trace the origin of seeds within E.Africa. In addition, inadequate tree seed testing facilities and poor formal distribution networks of forestry seed contributes significantly to the challenges in undertaking phytosanitary measures. Efforts and investments should therefore be made to ensure that stakeholders access high quality tree germplasm to guarantee sustainability of our forest resources. This paper therefore aims to create awareness on the status, challenges and opportunities that exist to ensure that phytosanitary measures are instituted for clean germplasm exchange.

Key words: Tree germplasm, exchange, pathogen and pest introductions, phytosanitary challenges, clean germplasm exchange

Introduction

The production, improvement, conservation and research on tree germplasm are major flagship projects at the Kenya Forestry Research Institute (KEFRI). The main goal of the institute is to meet the increasing demand of high quality germplasm for plantation and on-farm tree species locally, regionally and internationally. It is important to note that there has been a gradual decline in tree seed production in the last ten years (KEFRI Seed Report unpublished). This has been attributed to unpredictable flowering patterns due to changing climatic patterns resulting in reduction in seed production.

Over 90% of the tree species are propagated through seed which are raised as seedlings. Other types of propagation include grafts, cuttings and tissue culture to a lesser extent. In order to meet the increasing demand for high quality seed sources, KEFRI started to establish seed sources from 2010. To date the Institute has established and maintained approximately 1200 hectares of seed sources out of which 230 hectares comprise the highly demanded tree species for plantations and agroforestry that include; *Cupressus lusitanica*, *Pinus patula*, *Eucalyptus grandis, E. urophylla, E. camaldulensis, Grevillea robusta, Tectona grandis, Vitex keniensis, Casuarina equisetifolia, C. jughuniana, Markhamia lutea, Gmelina arborea, Melia volkensii, Acacia tortilis, Terminalia brownii, T. spinosa, T. Kilimandcharisca*, and Pine hybrids. The Institute is currently establishing seed sources for the endangered *such as Osyris lanceolata* among others.

Forest germplasm is complex and consists of two types; orthodox and non-orthodox or recalcitrant seeds. Examples of recalcitrant seeds include *Azadirachta indica*, *Vitex keniensis*, *Warbugia ugandensis, Prunus africana* among others. Orthodox seeds can be maintained for a long duration without deterioration under ambient conditions while recalcitrant seeds have short duration viability and are easily attacked by fungal diseases due to their pulpy nature. Forest tree seeds vary greatly in size, shape and texture.

Seed is the main medium of germplasm exchange worldwide. Therefore it is also the main means of disease and pest introduction in new localities worldwide resulting in non-native pest and disease invasion (Liebhold *et al.,* 2012). This paper explores the context phytosanitary challenges facing exchange of forest /tree germplasm and the efforts being put in place to mitigate some of the challenges and the way forward to ensure exchange of healthy tree germplasm in Kenya.

Seed Pathology

Microflora affecting seeds are mostly fungi, bacteria and to lesser extent, viruses. Seed infections can be (i) Internally seed borne where pathogen attacks the seed coat, endosperm and embryo, (ii) Externally seed borne where pathogens are externally carried over on seeds and or (iii) Surface contaminants where fungal fruit bodies or spores occur on the surface of seeds.

Seed infections result in (i) Poor germination from the effects of fungi that cause pre and post emergent damping off, (ii) Weak seedlings or reduced seedling growth vigour, (iii) Seed rots, leaf diseases such as spots, blights shoot tip deaths and sometimes whole seedling deaths which are reported to account to >80 % losses in tree nurseries (iv) Loss in market value of seeds and (v) Production of toxic chemicals that are harmful to humans and animals. Seed-borne micro-organisms include pathogens causing plant disease in the field and also during storage.

Trends in forest pathogens in Kenya

Tree diseases have been on the increase in Kenya.. The first major disease reported in Kenya are exotic pathogen, *Dothistroma pini* needle blight which had a catastrophic effect on *Pinus radiata* in East Africa (*Odera and Arap Sang, 1980)* and slowed down its plantingfrom the 1970s till now. Intensified research however shows that there may be some tolerant *P. radiata* genotypes in Timboroa, Kenya which could be exploited for plantation establishment (Mbinga, 2002).

Other introduced tree diseases include *Armillaria heimii* Pegler [*Armillariella elegans* (R. Heim) J.B. Taylor, J.E. Hawkins & McLaren; [*Clitocybe elegans* R. Heim., which causes root rots on many species of both broadleaves and conifers. It causes economic damage on *Pinus patula*. Another Armillaria species, *Armillaria mellea* (Vahl) P. Kumm., [*Agaricus melleus* Vahl; or *Agaricus sulphureus* Weinm.;] also causes root rot disease on many species of plants in Kenya.

Endophytes are also transmitted through seeds. For example an emerging group of pathogens falling in the Botryosphaeriaceae are spreading fast in Kenya. The Botryosphaeriaceae have been identified as important pathogens on the popular agroforestry tree species-*Grevillea robusta.* It is also widespread in multipurpose tree species that include *Melia volkensii, Senna siamea* and *Azadirachta indica* (Njuguna *et al.,* 2011; Njuguna, 2011). The Botrosphaeriaceae have also been proved to be seed-borne and also pathogenic on Montane Forest species; *Prunus africana* (Gure, 2005).

Likewise various diseases comprising of the Botryosphaeriaceae and the closely related Teratosphaeriaceae are reported to be on the increase on the genus *Eucalyptus* within Africa. Recent studies clearly indicate that in Kenya, these fungal pathogens are closely related to the importation of *Eucalyptus* clones and can be phylogenetically traced to fungi affecting the genus in South Africa, Latin America and Australia (Machua *et al.,* 2016).

Trends in forest pests in Kenya

Forest pests have also had catastrophic effects in Kenya since the 1960s. It is reported that most of the forest pests in Kenya have been accidentally introduced in Kenya with severe impacts to forest plantations (FAO, 2005). For example, *Cinara pinivora* Wilson, an aphid attacking *Pinus* species is not a native. It was introduced into Kenya and it is a threat to pine plantations in Kenya (Maina, 2005). The aphid attacks pine seedlings causing defoliation and mortality of affected plants. The good news is that the pest can be kept under control by insect predators belonging to Coccinellidae, Syrphidae, Chrysophidae, Staphilidae, Dermaptera and some Heteroptera (Penteado, 1995). Another non-native pest to several species of *Pinus* is the *Eulachnus rileyi* Williams [*Lachnus rileyi* Williams] commonly known as the pine needle aphid. Heavy infestation causes leaf fall and stunted growth of seedlings.

The genus *Cuppressus* has been attacked by an exotic forest pest is *Cinara cupressivora* Watson & Voegtlin, belonging to the order Hemiptera: Aphididae, commonly known as giant cypress aphid or cypress aphid. The aphid is known to attack conifers including, *Cupressus* spp.; *Juniperus* spp.; *Thuja* spp.; among others. The pest was first identified in Malawi in 1986 and quickly spread within East and southern Africa causing significant damage of dieback and total tree death. It arrived in Kenya in 1990 (Ciesla, 1991). However biological control agent *Pauesia juniperorum* was introduced in Kenya and has since significantly controlled the cypress aphid (Day *et al.*, 2003)., The most affected species was *Cupressus macrocarpa* and *Cupressus lusitanica.* Non-native pests of economic importance have been reported on Eucalyptus species in Kenya as shown in Table 1.

Table 1. Examples of non-native forest pests on Eucalyptus sp. in Kenya

Pest	**Arrival and Status**	**Remarks**
Glycaspis brimblecombei Moore (Eucalyptus red lerp gum psyllid)	October 2014 from South Africa and is spreading fast. The wind is a major agent in spread.	No action yet
Thamaustocoris peregrinus Carpintero et Dellape (Eucalyptus Winter Bronze bug)	Identified in Nov. 2009) widespread and spreads fast via weed.	Biological control is available (Mutitu *et al*., 2013)
Leptocybe invasa Fisher & La Salle (Blue Gum Chalcid)	Widespread in East Africa. It is known to have moved from Kisumu to Malindi in a day by road.	Biological control is available (Nyeko, 2010)

Pest	Arrival and Status	Remarks
Gonipterus sculletus Gyllenhal (Eucalyptus snout beetle)	Identified in 1926, widespread on Eucalyptus clones. It is reported that a wrong parasitoid (*Anafe nitens*) was released in 1930s hence the constant re-emergence.	Biological control?

In addition, the growth of *Leucaena leucocephala* a promising agroforestry tree species in Kenya was seriously hampered by the introduction of the pest *Heteropsylla cubana* Crawford [*Heteropsylla incisa*, (Sulc.)], commonly known as *Leucaena* psyllid. The pest also attacks *Albizia* spp.; *Mimosa* spp.; *Samanea saman*. The pest was reported in Kenya in 1992 (Reynolds and Bimbuzi, 1992).

Phytosanitary Challenges Affecting Tree Germplasm Exchange

According to Article V.2a of the IPPC (1997): *"Inspection and other related activities leading to issuance of phytosanitary certificates shall be carried out only by or under the authority of an official of national plant protection organization. The issuance of phytosanitary certificates shall be carried out by public officers who are technically qualified and duly authorized by the official national plant protection organization to act on its behalf and under its control with such knowledge and information available to those officers that the authorities of importing contracting parties may accept the phytosanitary certificates with confidence as dependable documents."* (See also ISPM Pub. No. 7: *Export certification system*). In Kenya, Phytosanitary certificates are issued by the Kenya Plant Health Inspectorate Service (KEPHIS).

The Seeds and Plant Varieties Act, CAP 326, Revised Edition 2012 [1991] further requires that all plant and animal products designated for export or import undergo specific tests to ensure that they meet the required phytosanitary standards for safety and to reduce risks of exporting or importing materials that may be detrimental or injurious to humans, animals and the environment. However in most cases materials are moved or exchanged between institutions and individuals without following the laid down procedures and regulations. Following is a summary of the phytosanitary challenges that face exchange of tree germplasm or reproductive material in Kenya.

a) Difficult to control movement of forest resources and forest products within and across countries

Movement of forest resources follow movement of human. Humans easily move from one area to another in search of livelihoods and settlement. In the process they move with everything including products such as timber, fuel wood, packaging materials, poles and posts through (i) Road networks that include road, rail, human, animal transport, (ii) Water transport through containerised shipments and package materials, (iii) Air transport and other means of transport. These movements are difficult to control because people do not declare what they carry for fear of losing them through confiscation by authorities. The porosity of our borders makes it even harder to control germplasm exchange. People living along the borders easly move materials without control. The border entry points to any country within East Africa further aid the exchange of uninspected materials through laxity and lack of requisite human and non-human skills.

b) Difficulties in control movement of live materials within and between countries

Most stakeholders /farmers do exchange all types of planting materials easily that include among others; seeds, cuttings and seedlings. These have been moved even across borders for afforestation programmes and projects. The most common and fast means of movement is "farmer to farmer" exchange between localities and even across borders. It has been observed that; the quality and health status of such materials is usually is not guaranteed. Liebhold *et al.*, (2012) reported that live plant imports introduce live pests and diseases into new regions and are the major pathways for the primary introductions of forest pests and pathogen invasions.. Further the study showed that continuous imports of reproductive materials may also introduce more virulent and or additional genotypes of a pathogen or pest thus altering its diversity and genetics.

c) Uncontrolled tree seed trade

Tree seed trade within East Africa is largely uncontrolled. There are inadequate legislations on tree seed trade. Most E.African countries use agricultural regulations and Kenya is no exception. Agricultural regulations still lack standards for control of health issues regarding tree seeds, more so for many indigenous species The trade is also riddled with huge variations in prices of forestry seed even of the same species in different areas within the same country. High quality tree seed sources are also inaccessible to a greater majority of stakeholders due to poor distribution channels of forestry seed. For example the Forestry Seed Centre (KFSC) is located at Muguga which is far from many stakeholders. In addition packaging of forestry seed is poor within the country due to the complex nature of forest germplasm, and that limits their distribution too.. The current ban on sale of polythene for packing is a draw-back to the newly designed packaging materials. It will take a while to design and test new packaging materials.

d) Inadequate traceability to source of forest germplasm

Although some sources have been selected and georeferenced, many seed sources do not have the required documentation on the origin of the seed. This causes traceability problem hence lowering pricing of seed.

e) Inadequate resources to support production, storage and exchange of high quality forest germplasm

Forest germplasm production and conservation is largely supported by funds from the exchequer which are not adequate to support all the required processes . The current annual allocation is Ksh 10,000,000 against a requirement of Kshs 75,000,000. There is also shortage of trained personnel in tree seed collection, processing, testing and certification. There are also inadequate storage facilities to meet national demand.

Mitigating the phytosanitary challenges faced in forest germplasm exchange

The Kenya Forestry Research Institute has initiated some measures to mitigate some of the challenges. These include;

a) Production of high quality tree germplasm

KEFRI produces on average 10 tons of tree seeds comprising of about eighty tree species which meets about 40% of national tree seed demand. Demand for tree seeds is expected to increase from the demands of the newly launched National Forests Programme (NFP) 2016-2030 whose major focus is expansion of commercial forestry and rehabilitation programmes. In some cases, KEFRI also imports reproductive materials (mainly seeds) of selected tree germplasm for mainly for research trials. The institute also produces forest reproductive materials that include grafts, cuttings, marcots among others for research purposes. Production and conservation of high quality tree germplasm involves selection of mother trees of identified tree species which meet specific characteristics among them free of pests and diseases. It also involves developing protocols to raise planting materials of difficult to propagate indigenous tree species that include *Terminalia brownii, Tectona grandis, Melia volkensii, Gmelina arborea, Markhamia lutea, Osyris lanceolata, Ocotea usambarensis, Maesopsis eminii* and *Terminalia spinosa* among others.

b) Amendment of the Seeds and Plant Varieties Act 2012 to include Tree Seed Regulations

The institute is the process of proposing an amendment to the Seeds and Plant Varieties Act 2012 to include Tree Seed Regulations. The amendment will guide and facilitate the production, conservation and trade in forest germplasm. It will also provide for guidelines on formation of a National Tree Seed Advisory Committee (NTSAC), registration of tree seed sources and tree seed merchants, tree seed inspection, collection, processing, sampling, testing, tree seed importation and exportation, packaging, labelling and sealing, validity certification and quality declaration and offences and penalties for breaking the rules stipulated under each section.

c) Ensuring tree seed traceability to source

The institute has made significant efforts towards ensuring that tree seeds going out of KEFRI can be traced to the source. KEFRI represents Kenya in the OECD Forest Seed and Plant Scheme as the Chair of the Tree Seed traceability committee. The institute is also currently working on registration and documentation of all information on available tree seed sources in the country. Though expensive, the activity is a priority to enable the institute to trade internationally and also for the seeds to attract better prices. Through compliance to the OECD regulations, the institute will ensure that establishment and management of tree seed sources meet international standards.

d) Building capacity of staff and stakeholders in forest/tree germplasm

Together with partners the institute will continue to build capacities of staff to carry out key activities such as collection, processing, testing and distribution of high quality germplasm. The institute is also building capacities of stakeholders in the above in addition to establishment, management of tree nurseries and tree resources. Sensitization campaigns on the importance of healthy materials and good forest management will be carried out countrywide through various media and fora.

e) Seed research and technology

The institute continues to carry out research on tree seed technology. This includes generating technologies to improve collection, processing, storage and germination of tree seeds among others. The focus is on developing technologies for germination of indigenous tree species as well as to establish testing standards for key species with collaborators that include OECD members, KEPHIS, World Agroforestry Centre (ICRAF), Seed Trade Association of Kenya (STAK), Kenya Seed Company and many other stakeholders to enhance exchange of healthy forest germplasm. The institute is already carrying out research in collaboration with ICRAF to develop a germplasm health quality management system (GH-QMS) for all ICRAF nurseries and field genebanks by 2020. The project is currently focussing on developing standards for *Grevillea robusta, Moringa oleifera, Sclerocarya birrea, Adansonia digitata, Berchamia bicolor, Vangueria rotundata* among others.

f). Establishment of a Tree Seed Certification Unit

The proposed amendment to the Seeds and Plant Varieties Act 2012 also provides for the establishment of the Tree Seed certification Unit. The unit will offer tree seed testing services and also phytosanitary certificates for tree seeds. This will be the first of its kind in the region. Resources to establish the unit and other tree seed activities are being mobilized from various sources including the exchequer.

g) Monitoring of forest pests and diseases

Forest health is critical to the exchange of health tree/forest germplasm. The institute carries out research aimed at developing pest and disease diagnostic technologies in order to improve pest /disease management support systems and advisory services to stakeholders especially on priority tree species. A forest health monitoring system has been put in place in all eco-regions to improve early detection of forest pests and diseases. The health team also seeks to understand the role of climate change on the emergence of "new" forest pests /diseases in order to devise appropriate management strategies.

Conclusions

From the foregoing it is clear that phytosanitary challenges to tree germplasm exchange require multi-stakeholder collaboration, establishment of partnerships and networks to ensure that stakeholders access high quality germplasm. Mobilization of resources is therefore key to facilitating and sustaining the mitigation activities outlined above.

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Early Growth Performance and Survival of Selected Pine Hybrids in Turbo and Muguga, Kenya

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Abstract

Pines have been among the major plantation species grown in Kenya as in many parts of the world. The narrow range of commercial plantation species, the risks associated with climate change and the needs to improve productivity per unit area have necessitated screening of new pine germplasm. A study was conducted to evaluate survival and early growth performance of 13 pine hybrids in Muguga and Turbo Kenya, with an objective of determining their potential for plantation forestry. Average survival of the hybrids across the two sites at five years was 61.8 % and varied from 26.4 % to 87.8 %. In each trial, the best-performing hybrid clones grew significantly faster ($P < 0.05$) than *P. patula* in height and diameter at breast height. Mean volume production for the hybrids was significantly higher in Muguga than Turbo ($P < 0.05$, V = 0.051). Relative performance of the best hybrid clones showed consistency in ranking for growth across the sites and analysis showed low genotype-by-environment interaction. Early selection indicates that *P. patula* x *P. tecunumanii* (low elevation) was the best hybrid for the two sites. The results suggest that five hybrids that performed better than the local *P. patula* could be used in establishing pilot plantations in major pine plantation areas in Kenya.

Keywords: Improved productivity, growth performance, genotypes, pines, pine hybrids

Introduction

Forest cover in Kenya has been dwindling over the years, and by 1990 it had reduced to less than 1 % of the country's land area (Wass, 1995). However, the recent estimates put the forest cover at about 7 % of the total land mass, with approximately 77 % being held in community and private lands. The current surge in tree cover is credited to the enhanced tree planting by small and large scale farmers with commercial intentions. It is estimated that about 220,000 hectares (ha) of Kenya's forest land is under plantations, contributing to about 3.6 % of the country's Gross Domestic Product (GDP) (Ministry of Environment and Natural Resources, 2016). Forest plantations, therefore, play a significant role in socio-economic development of the country, in addition to their environmental benefits. Furthermore, forest plantations have the potential to buffer the indigenous forests from overexploitation by providing most of the wood and non-wood forest products required by the forest adjacent communities and other users. Despite the important role played by forest plantations, the area under natural forests, which are mainly under the custody of the government, are still facing a downward trend, mainly due to overexploitation and degradation, as demand for forest products has far outstripped the supply. This scenario is predicted to continue into the future. A study carried out in 2013 by the Ministry of Environment and Natural Resources indicates that in 2012, Kenya had a wood supply potential of 31.4 million m^3 against a national demand of 41.7 million m^3, hence a deficit of 10.3 million m^3 with a projected deficit of 15 million m^3 in 2031-2032 (Ministry of Environment and Natural Resources, 2013). As the demand for wood and wood products increases, more plantations are needed to bridge the gap within the shortest time possible. This calls for identification and promotion of fast growing tree species with high survival and good quality wood products.

Currently, forest plantation species in Kenya largely include; *Eucalyptus grandis*, *E. saligna*, *Pinus patula* and *Cupressus lusitanica*. These species, together with *Pinus radiata* dominated the forest plantation industry since early 20th century, until recently when *Eucalyptus* hybrid clones were introduced. Unfortunately, some of these species have been prone to attack by pests and diseases, while performance of other species has been affected by climate change, thus necessitating new introductions to diversify the plantation species. For example, *Pinus patula* and *P. radiata* were introduced in Kenya in the early 1900s as a source of fiber for pulp and paper industry. However, cultivation of *P. radiata* was discontinued due to infestation by pine needle blight (Ivory, 1967). More recently, the attack by Cypress aphid, (*Cinara cupressivora*) on *C. lusitanica* threatened its continued planting until a biological control agent of the pest was introduced. In addition, survival and yield of *P. patula* has reduced in some of the areas popularly planted with the species, due to the prevailing dry conditions, probably brought about by climate change. Generally, yields of pine plantations in Kenya are much lower than those of pine hybrids in other countries including South Africa. The need to increase wood production per unit area has led to development of more options for sustainable improvement of the production of forest plantations in other parts of the world (Dieters and Nikles, 1997). One of the options is development of high yielding and fast growing hybrids. Interspecific hybrids of pines are used in forestry across a wide geographic range including Australia (Dungey *et al*., 2000), USA (Kubisiak *et al*., 1997), Brazil (Dieters and Nikles, 1997) and the African continent (Dvorak, 2001).

Through the international tree conservation and domestication program also known as Central American and Mexico Coniferous Resources Cooperative (CAMCORE), a number of pine hybrids have been developed and availed to members for trials (Leibing *et al*., 2009). There is substantial information indicating that hybrids outperform pure parental species due to heterosis in many tropical and subtropical regions (Blanco and Lambeth, 1991). The majority of hybrids planted are generally from the first generation crosses, but the second generation or advanced generation is often considered because it is conceptually easy to produce in an open-pollinated seed orchard (Byun *et al*., 1989). For example, first generation of *P. elliotii* x *P. caribaea* hybrid is used in plantation forests of Queensland, Australia (Dieters and Nikles, 1997), and these hybrids are also being tested amongst other species combinations in China (Dungey *et al*., 2000). In Zimbabwe, the main hybrids under testing are *P. caribaea* x *P. tecunumanii* and *P. oocapa* x *P. elliotii* (Gwaze *et al*., 1999). Despite the low productivity of pine species in Kenya, no hybrid has been tried for improved production. Furthermore, uncertainty regarding the effect of potential climate change on the future commercial range of pine plantation also calls for detailed information on survival and growth performance among the potential genotypes (Dipesh *et al*., 2015).

Through collaboration with CAMCORE, 13 pine hybrids were introduced by the Kenya Forestry Research Institute (KEFRI) for screening in Kenya. The objective of the study was to evaluate survival and growth performance of the 13 pine hybrids on two sites: Muguga and Turbo; and to determine their potential for plantation forestry. This paper provides a comprehensive assessment of survival and growth performance of the 13 pine hybrids compared to a local collection of *P. patula* on the two sites. The results provide insight into the potential future germplasm for diversification and improved plantation forestry in Kenya.

Materials and Method

Site description

Pine hybrid performance trial was carried out in two sites in Kenya namely; Muguga and Turbo. Muguga site is found at 01°12′55.1″S and 036°38′45.6″E with elevation of 2070 metres above sea level (masl). The site receives between 350 mm and 1200 mm of rainfall with mean annual precipitation of 980 mm and temperature of 21 °C. The soil is dark reddish brown, sandy clay loam texture with moderate drainage. The soil is acidic (pH $CaCl_2$ = 5.1) with high amounts of nitrogen (% N = 0.4) and potassium (Kppm = 1002.9), but low phosphorus (Pppm = 4.9). The Turbo site lies at 0°38′ 2.265″ N and 035°3′ 45.62″ E at an altitude of about 1859 masl with a mean annual temperature of 18.3 °C. The mean annual rainfall is approximately 1500 mm and falls mainly between the months of May and September. The soils are dark brown, sandy clay loam with moderate drainage, pH $CaCl_2$ = 4.4, low carbon % with C = 1.31, phosphorus (Pppm) = 6.53, nitrogen (N) = 0.18 and potassium (Kppm) = 376.3.

Site preparation

Muguga site was formally under *P. patula* plantation, which was clear-felled in 2008. At the time of land preparation, the area was covered by tall bushes of about 3 m high with a thick undergrowth. The bushes were slashed and debris burnt. The site was then hoed by hand in between the stumps. At Turbo, the site was also previously planted with *P. patula,* which was clear-felled in 2002. The site was cultivated with agricultural crops in 2003, after which it stayed fallow and was invaded by grass and scattered Acacia bushes until the time of this experiment. The site was prepared by first uprooting the Acacia bushes and then ploughing with a tractor.

Trial establishment

On both sites, the trials were established in May 2011 using 13 pine hybrids and a local collection of *P. patula* as the control. Out of the 13 hybrids, 6 were represented in Muguga and 11 in Turbo (Table 1). Only five hybrids (*P. patula* x *P. gregii*, *P. patula* x *P. oocarpa*, *P. patula* x *P. tecunumanii* (high elevation), *P. patula* x *P. tecunumanii* (low elevation) and *P. tecunumanii* (high elevation) x *P. oocarpa*) were represented at both sites. The experimental design was 36 (6 x 6) tree plots with four replicates for Muguga and 49 (7 x 7) tree plots with three replicates for the Turbo site. The spacing between individual trees was 3 x 3 m on both sites. Two guard rows of *P. patula* were planted around the trials. The trials were assessed at five years for survival (physical counts), height and DBH (1.3 m above the ground) growth. Stem volume for individual trees was estimated using the following equation for juvenile trees (Ladrach and Mazuera, 1978):

$$V = 0.00003\ (DBH^2 * H),$$

Where, V is the individual tree stem volume (m^3), DBH is the diameter at breast height (cm), and H is the total tree height (m).

Table 1. List of pine hybrids used in the growth performance trials at Muguga and Turbo in Kenya

Code	**Hybrid**	**Site**	
		Muguga	**Turbo**
Car x Ell	*Pinus caribaea* x *Pinus elliotii*	Y	
Pat x Grs	*Pinus patula* x *Pinus greggii*	Y	Y
Pat x Ooc	*Pinus patula* x *Pinus oocarpa*	Y	Y
Pat x TecH	*Pinus patula* x *Pinus tecunumanii* (high elevation)	Y	Y
Pat x TecL	*Pinus patula* x *Pinus tecunumanii* (low elevation)	Y	Y
TecH x Ooc	*Pinus tecunumanii* (high elevation) x *Pinus oocarpa*	Y	Y
Control	*Pinus patula*	Y	Y
Car x TecL	*Pinus caribaea* x *Pinus tecunumanii* (low elevation)		Y
Ell x Car	*Pinus elliotii* x *Pinus caribaea*		Y
Ell x Tae	*Pinus ellliotii* x *Pinus taeda*		Y
Ell x TecH	*Pinus elliotii* x *Pinus tecunumanii* (high elevation)		Y
Pat x Ell	*Pinus patula* x *Pinus elliotii*		Y
Tecl x Car	*Pinus tecunumanii* (low elevation) x *Pinus caribaea*		Y

Note: Y denotes planting at the site

Data analysis

All data were analyzed using GenStat 18th edition statistical software package (Payne *et al*., 2015). Analyses of Variance (ANOVA) at the 0.05 significance level and least significant difference (LSD) tests were calculated for height, DBH and tree volume using the GLM procedure.

Results and Discussion

Survival

The overall survival was 63.6 % in Turbo and 64.4% in Muguga (Tables 2 and 3, respectively). However, the survival of the hybrids varied between 22.4 % and 84.4% at Turbo and between 46.5 % and 80.6% at Muguga. Overall, the hybrids had comparable survival to *P. patula* (58.5%), which is the dominant commercial pine species in the country. On either site, the survival of *P. patula* x *P. tecunumanii* was generally high compared to *P. patula* despite the differences in environmental factors such as rainfall, soil characteristics and elevation. Similar superior survival of pine hybrids compared to *P. patula* and *P. radiata* was recently reported by Hongwane *et al*. (2017). Survival rate in general is influenced by several factors, which may include site management, especially the weeding frequency and the protection of the seedlings from pests and diseases (Nilsson, 2012). Drought and seedling handling during planting period also contribute significantly to the survival rate. However, for the present trial, low survival rates in some genotypes may be attributed to poor handling and post-planting disturbances by both human, as well as domestic and wild animals.

Growth performance at Turbo site

Similar growth trend was observed for the hybrids in both height and DBH at the Turbo site. Both growth parameters revealed statistically significant differences ($P < 0.001$) among the hybrids. These results indicate that some selection may be required in order to choose the best genotypes for high productivity. However, the ranking in performance of the hybrids was different for both growth traits even though the rank for the best and least performing hybrids for the two parameters remained the same (Table 2). The highest height and DBH growth was observed in *P. patula* x *P. tecunumanii* (low elevation) followed by *P. patula* x *P. oocarpa*. The least height and DBH growth was realized in *P. elliottii* x *P. tecunumanii* (high elevation). For both height and DBH growth, *P. patula* performance was average relative to that of the hybrids. Similar results of superior performance of hybrids over pure species have been reported for pines and eucalyptus across the globe (Balozi *et al*., 2010; Eksteen, 2012; Cappa *et al*., 2013). The trees at Turbo had an average volume of 0.033 m^3 with a treatment range of 0.001 to 0.051 m^3. The volume production of the local *P. patula* was lower than the mean value and ranked 7^{th} compared to the hybrids. The superior performance of the hybrids may be attributed to the effective selection and breeding program, and provides an opportunity for widening pine gene pool in the country.

Table 2. Mean growth comparisons of pine hybrids at Turbo Kenya

Hybrid	Survival (%)	Height (m)	DBH (cm)	Volume (m^3)
Ell x TecH	22.4	2.499a	2.88a	0.001a
Ell x Tae	64.6	4.825b	6.82b	0.011b
Pat x Grs	59.2	6.485c	10.24c	0.024c
Ell x Car	77.6	6.694c	10.81cd	0.027cd
Car x TecL	68.7	7.514d	11.46d	0.031de
Pinus patula (control)	58.5	7.822de	11.31d	0.032de
Pat x Ell	38.1	7.602d	11.21d	0.033e
Tecl x Car	81.6	7.727d	11.5d	0.034e
TecH x Ooc	75.5	8.277ef	11.61d	0.036e
Pat x TecH	63.3	8.372fg	12.73e	0.043f
Pat x Ooc	69.4	8.632fg	13.26e	0.048fg
Pat x TecL	84.4	8.799g	13.55e	0.051g
Mean	63.6	7.104	10.615	0.033
LSD		0.28	0.58	0.005
SED		0.14	0.29	0.002
F-Probability (P = 0.05)		<0.001	<0.001	< 0.001

Note: The means were separated using Tukeys test

Growth parameters at Muguga site

A similar growth trend was found at the Muguga site as was reported for the Turbo site (Table 3). Significant differences were observed among hybrids for both height and DBH growth (P < 0.001). Just like in the Turbo site, *P. patula* x *P. tecunumanii* (low elevation) showed superior growth in both height and DBH. However, this was followed by *P. patula* x *P. tecunumanii* (high elevation) (Table 3), while *P. patula* x *P. greggii* hybrid showed the least growth for both height and DBH. These parameters were significantly different from those recorded for *P. patula*. The average stem volume was 0.051 m^3 with the treatment ranging from 0.035 to 0.084 m^3. In comparison to the six pine hybrids that were tested in this site, *P. patula* ranked fourth in terms of growth and productivity. This is an indication that there is an opportunity for introduction of the hybrids to enhance wood production in the area. However, it should be borne in mind that the *P. patula* seedlings used in the present study were not raised from selected superior individual trees. In this case, proper selection may lead to different results.

Table 3. Mean growth comparisons of pine hybrids at Muguga Kenya

FAM	Survival (%)	Height (m)	DBH (cm)	Volume (m^3)
Pat x GRs	54.9	6.93a	12.13a	0.035a
Car x Ell	54.9	7.32ab	12.55ab	0.038a
Pat x Ooc	75.6	7.76b	12.79ab	0.046b
P. patula	77.0	8.18c	13.06b	0.046b
TecH x Ooc	46.5	8.56cd	13.49b	0.051b
Pat x TecH	61.1	8.94d	14.88c	0.063c
Pat x TecL	80.6	10.50e	15.97d	0.084d
Mean	64.4	8.32	13.45	0.051
LSD		0.270	0.520	0.007
SED		0.138	0.265	0.004
F-Probability (P = 0.05)		< 0.001	< 0.001	< 0.001

Note: The means were separated using Tukeys test

Comparison of growth parameters between Muguga and Turbo sites

Comparison of growth performance for the five hybrids that were tested on both sites showed statistically significant differences ($P < 0.001$) for both site and growth parameters (Table 4). The interaction between treatment and site was also statistically significant. *Pinus patula x P. tecunumanii* hybrid was ranked first on both sites. However, there was significant difference between the two sites. Generally, trees in Muguga had significantly higher growth performance compared to the Turbo site. For example, trees at Turbo had an average volume of 0.037 m^3, with a mean range from 0.022 to 0.049 m^3 (Table 4), while at Muguga, the average volume was 0.056 m^3 with individual hybrid means ranging from 0.037 to 0.085 m^3. The volumes were comparable to those reported for *P. patula* x *P. tecunumanii* hybrid trial in South Africa at age five years (Kanzler *et al*., 2012). Similar results were reflected in both height and DBH measurements. Thus, the overall site quality in Muguga including high elevation appears to favour growth of the hybrids compared to Turbo. Based on the sample analyses, soils at Muguga also appeared to be more fertile compared to the Turbo site, which might have promoted superior growth of the hybrids. The average height, DBH and volume across the sites showed that *P. patula* x *P. tecunumanii* (low elevation) ranked first, whereas *P. patula* x *P. greggii* ranked last. At the Turbo site, however, *P. patula* x *P. oocarpa* hybrid ranked second. These results are similar to those reported by Hodge and Dvorak (2012) which indicated a potential gain for 'new' species. However, *P. patula* which is the main pine plantation in the area ranked distant fourth, suggesting that new pine germplasm could be introduced for improved production. Significantly higher performance of pine hybrids against *P. patula* has also been reported in South Africa (Nel *et al*., 2006)

Table 4. Mean growth comparisons of pine hybrids at Turbo and Muguga, Kenya

Hybrid	Muguga			Turbo			Combined		
	Height	**DBH**	**Volume**	**Height**	**DBH**	**Volume**	**Height**	**DBH**	**Volume**
Pat x GRs	7.00	12.35	0.037	6.47	10.23	0.022	6.76	11.56	0.031
Pat x Ooc	7.87	13.18	0.050	8.64	13.25	0.046	8.16	13.2	0.048
P. patula	8.21	13.14	0.046	7.81	11.33	0.031	8.02	12.47	0.040
TecH x Ooc	8.56	13.56	0.051	8.29	11.61	0.034	8.43	12.84	0.044
Pat x TecH	8.94	14.93	0.065	8.39	12.74	0.042	8.69	14.12	0.055
Pat x Tecl	10.55	16.11	0.085	8.81	13.56	0.049	9.82	15.16	0.070
Mean	8.52	13.88	0.056	8.07	12.12	0.037	8.31	13.23	0.048
LSD							0.2615	0.5243	0.004
SED							0.1333	0.2673	0.002
F-Probability							<0.001	<0.001	<0.001

*Units: H = m, DBH = cm, Volume = m^3

Conclusions and recommendations

This is the first field experiment of pine hybrids in Kenya and the excellent early growth performance of some of the hybrids at the two sites is encouraging. The results show that some of the hybrids, particularly *P. patula* x *P. tecunumanii* (low elevation) and *P. patula* x *P. tecunumanii* (high elevation) had better growth than *P. patula*, which is the common commercial pine species grown in Turbo and Muguga. This indicates that pine hybrids have a great potential for commercial forest plantation in Kenya and supports introduction of new plantation germplasm in the country. However, additional research should be carried out before implementing these findings because *P. patula* seedlings used in the trials were not from selected superior individuals, hence performance of the species might not have reflected that of selected local materials.

We recommend establishment of pilot plantations of *P. patula* x *P. tecunumanii* (low elevation) and *P. patula* x *P. tecunumanii* (high elevation) in the country, and further introductions of pine hybrids for trial in other ecological zones of the country

Acknowledgements

Gatsby and Kenya Forestry Research Institute (KEFRI) through Forest productivity and Improvement (FPI) thematic area funded the study. We thank the Members of CAMCORE who generously provided the hybrid materials and CAMCORE staff of North Carolina State University for coordination and assisting in design of trials. We recognize technical staff at KEFRI Muguga and Turbo Centres for their contribution in establishment, maintenance and assessment of the trials. The cuttings were raised at the Tree Biotechnology Trust Nursery of the Kenya Forest Service.

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Growth Performance of *Pinus kesiya* Royle ex Gordon Provenances in Poor Soils of Turbo and Nzoia, Kenya

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Abstract

Due to increased deforestation and effects of climate change, there was a need to diversify plantation species grown in Kenya. In addition, areas with good soil characteristics are under food crop production, thus limiting the land available for forest plantations. *Pinus kesiya* is native to Asia and grown in some African countries. The wood is used for construction, making furniture, pulpwood and fuelwood. The species has potential to grow in poor soils. The main objective of the study was to assess adaptability, growth performance, productivity and genetic variation of *P. kesiya* provenances. Fifteen *P. kesiya* provenances from Philippines and 5 from Zambia ex-Philippines were established in 2 sites with poor soils in Turbo and Nzoia in Western Kenya. Data was collected for survival, height and diameter at breast height (DBH) up 17.6 years of age, and subjected to Analysis of Variance. The trial in Turbo site was written off due to poor survival. At the Nzoia site, there were highly significant differences among provenances within years for mean survival, height, DBH and volume ($p \leq 0.001$). Mean height ranged between 19.7 and 25 m; DBH between 24 and 28 cm; volume between 31 and 47 m^3/ha/yr, while survival was 13 to 58 % at 17.6 years. Performance of *P. kesiya* in this study was good but lower than for other countries probably due to poor soils where the trial was established. This indicates the species could be considered as a plantation species on poor soils and in breeding programs.

Keywords: *Pinus kesiya*, growth performance, poor soils, provenances

Background

Pinus kesiya Royle ex Gordon is native to South East Asia (Louppe *et al*., 2008) but it is also widely grown in African countries including South Africa and Malawi (Missanjo and Matsumura, 2016). The species is fast-growing and has a wide geographical range. *Pinus kesiya* has many uses such as pulpwood, timber and resin extracts (Nyunai, 2008; Lamprecht, 1990).

In 1960s and 70s, many pine species in Kenya and other pine growing countries in Africa were affected by Diplodia die back (Arap-Sang, 1978) and *Dothistroma septosporum* (Barnes *et al*., 2004). *Pinus radiata* D. Don, which was one of the most important species grown for pulpwood and timber, was one of the most affected (Mathu, 2011). In addition, *P. patula* Schiede ex Schltdl. & Cham., another widely grown species, was also found to be susceptible to Diplodia infection , particularly in Turbo, a site with highly variable laterite soils. This necessitated further identification of additional plantation species.

Pinus kesiya shows good growth performance on poor and harsh sites in areas more than 1200 metres above sea level (masl) and with annual rainfall above 1700 mm (Hansen *et al*., 2003), hence the need to introduce the species for trials in Kenya. Provenance trials of *P. kesiya* have been established in several countries in the world (Missanjo and Matsumura, 2016; Hansen *et al*., 2003; Chamshama *et al*. 1990). The species was first introduced into Zambia in 1950s followed by more introductions to Brazil, Myanmar, China, Madagascar, Philippines, Thailand, Vietnam and Zimbabwe where high survival was reported in some cases (Hansen *et al*. 2003). The main objective of these trials was to explore genetic variability and adaptive traits in *P. kesiya* provenances with the aim of availing quality seed sources and their conservation (Hansen *et al*. 2003).

A *P. kesiya* provenance trial was established in Kenya in 1972. Objectives of the trial were to i) assess adaptability, growth performance and productivity for different uses, and ii) determine the extent and pattern of genetic variation of the introduced material.

Materials and Methods

Site

The pines were planted in Turbo, which lies in western part of Kenya at 0^{o} 38’ N and 35^{o} 4’E. The experiment was carried out on two sites; Nzoia and Turbo with the site characteristics as shown in Table 1.

Table 1. Site characteristics of Nzoia and Turbo sites

Characteristic	Nzoia site	Turbo site
Altitude	1,700 m asl	1,830 m asl
Rainfall	1,320 mm	1,250 mm
Soil	Shallow medium clay. Likely to be acid and deficient in Nitrogen (N) and Phosphorus (P). Soil less than 1 m deep	Very shallow dark reddish brown medium clay underlain with laterite 60cm. Moderately acid and deficient in Ca and P. Soil 30-80 cm deep
Vegetation	Grassland dominated by *Hyparrhenia filipendula*, *Themeda triandra* with acacia; *Combretum* sprouting from cut stumps	Maize to 3m at 0.9m spacing between rows, every third row of maize having been removed for trees. Also some herbs grass with wattle regeneration
Slope	Gentle N.W.	Level
Temperature	Mean annual hottest month = 29°C Mean annual coldest month = 18°C	Mean annual hottest month = 29°C Mean annual coldest month = 11°C

Seed sources

Twenty *P. kesiya* seed sources were introduced from Philippines and Zambia with fifteen and five provenances, respectively. Details of the various provenances are given in Table 2.

Table 2. Sources of *P. kesiya* provenances and other pine species grown in Nzoia and Turbo, Kenya

Seed no.	Latitude (°N)	Longitude (°E)	Altitude	Source
PK 9254	18° 15'	120° 51'	990-1140	Ilicos Norte (Lamin)
PK 9255	17° 53'	120° 44'	760-910	Ilicos Norte (Mt. Semene Blen)
PK 9256	17° 33'	120° 47'	1220-1280	Abra (Langangilang)
PK 9258	16° 54'	120° 55'	1550-1680	Bontoc (Mt. Data)
PK 9259	16° 54'	120° 53'	1950	Bontoc (Mt. Data)
PK 9261	16° 51'	120° 45'	980-1130	Benguet (Lapanto)
PK 9262	16° 39'	120° 51'	2160	Benguet (Kabeyan)
PK 9263	16° 19'	120° 51'	1160-1310	Neuva Viscaya (Kayapa)
PK 9264	16° 09'	120° 49'	980	Pangasinan (San Nicolas)
PK 9265	16° 06'	121° 06'	910-1100	Neuva Ecija (Mt. Otang)
PK 9266	16° 01'	121° 10'	910-1100	Neuva Ecija (Mt. Benbeu)
PK 9267	16° 00'	121° 08'	60-790	Neuva Ecija (Mt. Tilasacana)
PK 9269	15° 32'	120° 07'	910-1130	Zambales (Coto mine)
PK 9270	15° 32'	120° 07'	610-760	Zambales (Coto mine)
PK 9271	16° 30'	120° 50'	1520-2130	Benguet (Bokod)
PK 9533	Zambia, Chichele		1280	Vietnam origin
PK 9548	Zambia, Samfya			Philippines origin
PK 0568	Zambia, Samfya			Philippines origin
PK 0574	Zambia, Chati		1200	Madagascar origin
PK 0591	Zambia, Chichele		1280	Vietnam origin
P. radiata	Kitiri, Kenya		2400	Cpt. 12.A Collected 1969
P. caribaea var.	*Bahamensis* 69 (7296)		3	Andros Island
P. oocarpa NSB.14			910	Guatemala

Note: PK denotes *Pinus kesiya*

Experimental design and layout

Planting was done at a spacing of 2.5 m × 2.5 m for Nzoia site and 2.7 m × 2.7 m for Turbo site. Balanced lattice design was used with three and six replications for Turbo and Nzoia sites, respectively. The plots were 5 × 5 trees, with the centre 3 × 3 being assessed.

Assessment and data analysis

Height was assessed periodically for 17 years, while DBH was assessed from 5 to 17.6 years. Analysis of Variance (ANOVA) was used to compare the means for height, DBH and volume for *P. kesiya* in this trial while Kaplan-Meier procedure was used to compare tree survival over time. Tree volume was calculated using the formula:

Tree volume (m^3) = $[(DBH/200)^2 \times 3.142 \times height]/3$

Mean annual increment (MAI) was calculated by dividing volume by age and periodic annual increment (PAI) by dividing the volume between successive times by successive time periods. Analysis of Variance was calculated using unbalanced design in Genstat Statistical Package version 15 (Payne *et al*., 2014).

Results

Although the trials were established in two sites; Turbo and Nzoia, trees in the Turbo trial were initially damaged due to rats and later affected by heavy mortality in all provenances and species except *P. radiata* within the first year of planting. The trial was hence written off. Results presented are therefore for Nzoia site only.

Survival

Generally, the whole trial had a low average survival rate of 37 % over the entire growth period although different provenances showed varied performance: for instance, PK 9269 had moderate survival rates with a mean of 58.7% followed closely by Chichele with 57.1 % while the lowest survival was observed for PK9262 and PK9265 with 20.4 % and 13 %, respectively. There were high significant differences between the provenances and over time (p=0.000) using Log Rank, Breslow and Tarone-Ware, all for comparing equality of survival distributions. Survival at Nzoia site was high for most provenances at 2.8 years of above 50 % except for PK9262 and PK9265 with 22.2 % and 25.9 %, respectively (Figure 1). At 5.6 years, survival rate for the whole trial was 54 %, down from the initial 71 % at age 2.8 years. Provenance 9264 and PK 9269 had the highest survival of 72.2 %, followed by PK 9548 and Chichele of 70.4 % each, while the lowest survival was recorded for PK 9265 (22%) (Figure 1). The total survival reduced to 43 % at 10.4 years and further to 39 % by age 17.6 years. Chichele and PK 9269 provenances had the highest survival at both ages above 55 %, while PK 9265 was lowest with less than 20 % (Figure 1).

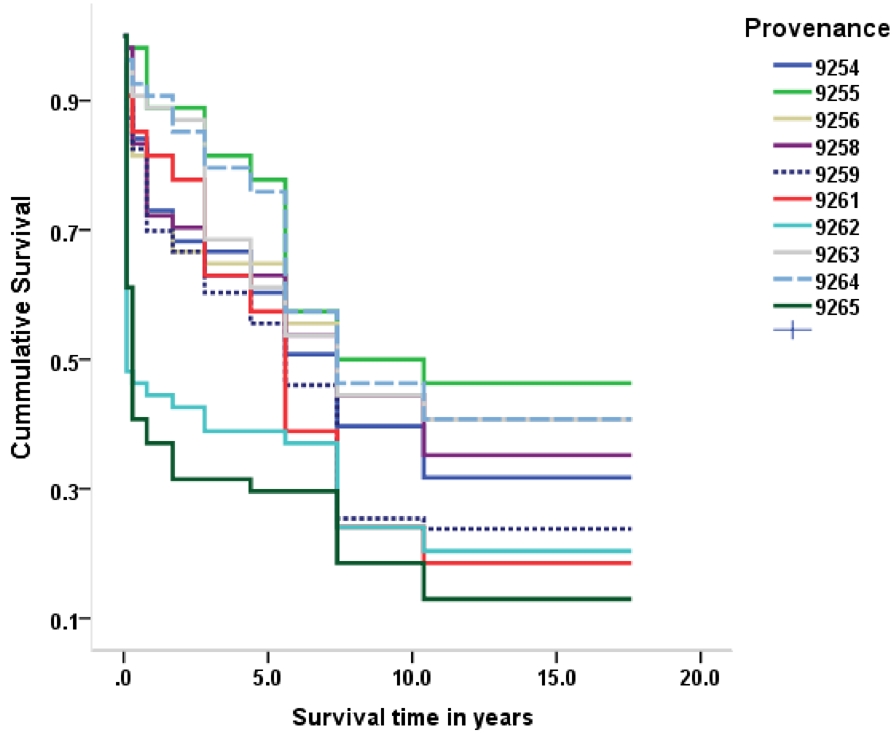

Figure 1. Cumulative probability survival rates for *P. kesiya* provenances over time in Nzoia Kenya

Height

There were high significant differences for height growth among provenances within all the years ($p \leq 001$), except at age 7.4 years, where there were no significant differences (Table 3). At age 2.8 years, PK 9263 showed highest height of 2.4 m followed closely by PK 9548 at 2.39 m, while the lowest was PK 9259 (Table 3). At age 5.6 years, PK 9263 still showed the highest mean height of 7.73 m, followed by PK 9269 of 7.50 m, with the lowest as Chichele with 6.25 m. At age 10.4 years, the difference between highest and lowest mean height had increased to 2.4 m with the highest as PK 9263 with 15.67m and the lowest as PK9262. The best performance at 17.6 years was observed for PK 9263 with 24.59 m followed closely by Chati, while lowest was still PK 9262 with 4.9 m less (Table 3).

Diameter at Breast Height

In general, DBH showed significant differences among provenances ($p \leq 0.001$ and $p \leq 0.05$) within all ages except at age 10.4 years, where there were no significance differences (Table 4). Chati showed the highest mean DBH at age 5.6 years of 12.04 cm followed by PK 9263. At age 7.4 years, Chati provenance continued to hold the top position followed by PK 9271, through to age 10.4 years, while PK 9259 still showed the least performance at age 7.4 years (Table 4).

Diameter at breast height at age 17.6 years was highest for PK 9267 with 28.80 cm followed by PK 9265 (Table 4).

Table 4. Performance of DBH for *P. kesiya* provenances over time in Nzoia, Kenya

	DBH over time (cm)			
Provenance	5.6 yrs	7.4 yrs	10.4 yrs	17.6 yrs
PK 9254	10.44 bcde	15.88 abc	21.08	27.42 ab
PK 9255	10.49 bcde	16.14 abc	20.53	24.00 b
PK 9256	10.39 bcde	16.27 abc	21.70	26.42 ab
PK 9258	10.61 bcde	15.00 cde	19.97	24.71 ab
PK 9259	9.47 e	14.04 e	19.75	26.67 ab
PK 9261	10.85 bcd	15.80 abcd	22.08	27.58 ab
PK 9262	9.72 de	14.39 de	19.76	23.94 b
PK 9263	11.31 ab	16.30 abc	21.32	25.27 ab
PK 9264	10.98 abc	16.39 abc	20.64	25.32 ab
PK 9265	10.65 bcd	15.76 bcd	21.94	27.70 ab
PK 9266	11.24 abc	16.28 abc	20.82	26.37 ab
PK 9267	10.11 cde	15.96 abc	21.18	28.08 a
PK 9269	10.33 bcde	16.38 abc	20.72	26.34 ab
PK 9270	10.48 bcde	15.62 bcd	20.91	26.10 ab
PK 9271	11.10 abc	16.98 ab	21.66	26.55 ab
PK 9533	10.76 bcd	16.32 abc	21.35	26.30 ab
PK 9548	11.17 abc	16.04 abc	20.43	25.60 ab
Chati	12.04 a	17.24 a	22.09	25.89 ab
Chichele	10.14 cde	15.16 cde	19.71	23.90 b
Samya	11.12 abc	16.37 abc	22.02	27.51 ab
Sig diff	< 0.001	< 0.001	ns	0.037
SED	0.5756	0.7304	1.118	1.884
CV (%)	18.86	15.50	16.57	20.65

NB: Ranking was done using LSD at 5%

Volume

The volume had a similar trend like that for height and DBH with significant differences among provenances across the years ($p \leq 0.01$ and $p \leq 0.05$) (Table 5). Volume at age 5.6 years showed that Chati ranked highest followed by PK 9263. At age 10.4 years, Chati was still the best with 29.6 m^3/ha/yr followed closely by PK 9263, while the lowest ranking was Chichele (Table 5). PK 9267 showed highest volume of 46.9 m^3/ha/yr at 17.6 years followed closely by PK 9261, while lowest were PK 9255 and Chichele (Table 5).

Table 5. Performance of *P. kesiya* provenances in volume over time at Turbo site, Kenya

	Volume and mean annual increment (m^3/ha/yr) over time (years)							
	5.6 yrs		**7.4 yrs**		**10.4 yrs**		**17.6 yrs**	
	Volume	**MAI**	**Volume**	**MAI**	**Volume**	**MAI**	**Volume**	**MAI**
Provenance								
PK 9254	5.78 bcde	1.03	14.75 ab	1.99	24.70 abcd	2.36	41.37 ab	2.35
PK 9255	6.19 abcde	1.11	16.00 ab	2.16	25.07 abcd	2.41	31.37 b	1.78
PK 9256	6.10 abcde	1.09	16.33 ab	2.21	27.81 abcd	2.67	41.25 ab	2.34
PK 9258	6.20 abcde	1.11	13.30 ab	1.80	23.08 bcd	2.22	32.87 b	1.87
PK 9259	4.72 e	0.84	10.97 b	1.48	22.31 d	2.15	36.80 ab	2.09
PK 9261	6.55 abcde	1.17	15.21 ab	2.06	28.90 abc	2.78	46.40 a	2.64
PK 9262	4.83 de	0.86	12.83 ab	1.73	22.83 cd	2.20	32.58 b	1.85
PK 9263	7.85 ab	1.40	17.09 ab	2.31	29.23 ab	2.81	38.27 ab	2.17
PK 9264	7.08 abcd	1.26	16.84 ab	2.28	25.22 abcd	2.43	38.33 ab	2.18
PK 9265	6.44 abcde	1.15	15.27 ab	2.06	28.96 abc	2.78	41.29 ab	2.35
PK 9266	7.16 abc	1.28	16.07 ab	2.17	26.21 abcd	2.52	38.07 ab	2.16
PK 9267	5.71 bcde	1.02	15.55 ab	2.10	27.93 a	2.69	46.87 a	2.66
PK 9269	6.34 abcde	1.13	17.51 a	2.37	26.83 abcd	2.58	41.31 ab	2.35
PK 9270	6.59 abcde	1.18	16.03 ab	2.17	27.07 abcd	2.60	38.29 ab	2.18
PK 9271	7.07 abcd	1.26	17.40 ab	2.35	28.15 abcd	2.71	36.28 ab	2.06
PK 9533	6.33 abcde	1.13	15.71 ab	2.12	26.64 abcd	2.56	38.98 ab	2.21
PK 9548	7.21 abc	1.29	16.62 ab	2.25	24.79 abcd	2.38	36.76 ab	2.09
Chati	8.16 a	1.46	18.51 a	2.50	29.62 a	2.85	40.91 ab	2.32
Chichele	5.18 cde	0.93	12.75 ab	1.72	22.21 d	2.14	31.40 b	1.78
Samya	6.97 abcde	1.24	16.43ab	2.22	28.72 abc	2.76	40.46 ab	2.30
Sig. diff	0.003		0.049		0.05		0.05	
SED	1.14		3.24		3.08		6.36	
CV (%)	47.53		68.10		37.56		47.03	

NB: Ranking was done using LSD at 5%: High CV attributed to high variation in survival for the trees within the provenances

Mean annual increment (MAI) ranged between 0.9 and 2.9 m^3/ha/yr (Table 5), while periodic annual increment (PAI) was 0.9 to 6.2 m^3/ha/yr for all provenances (Fig. 2). Generally, PAI reduced over time where the highest PAI was recorded at age 7.4 years for PK 9269, followed by

Chati of 6.2 m^3/ha/yr and 5.8 m^3/ha/yr, respectively (Fig. 2). At age 10.4 years, PK 9261 and PK 9265 showed the highest PAI of 4.6 m^3/ha/yr, while at age 17.6 years PK 9267 ranked highest with 2.6 m^3/ha/yr followed closely by 9261 showing 2.4 m^3/ha/yr (Fig. 2).

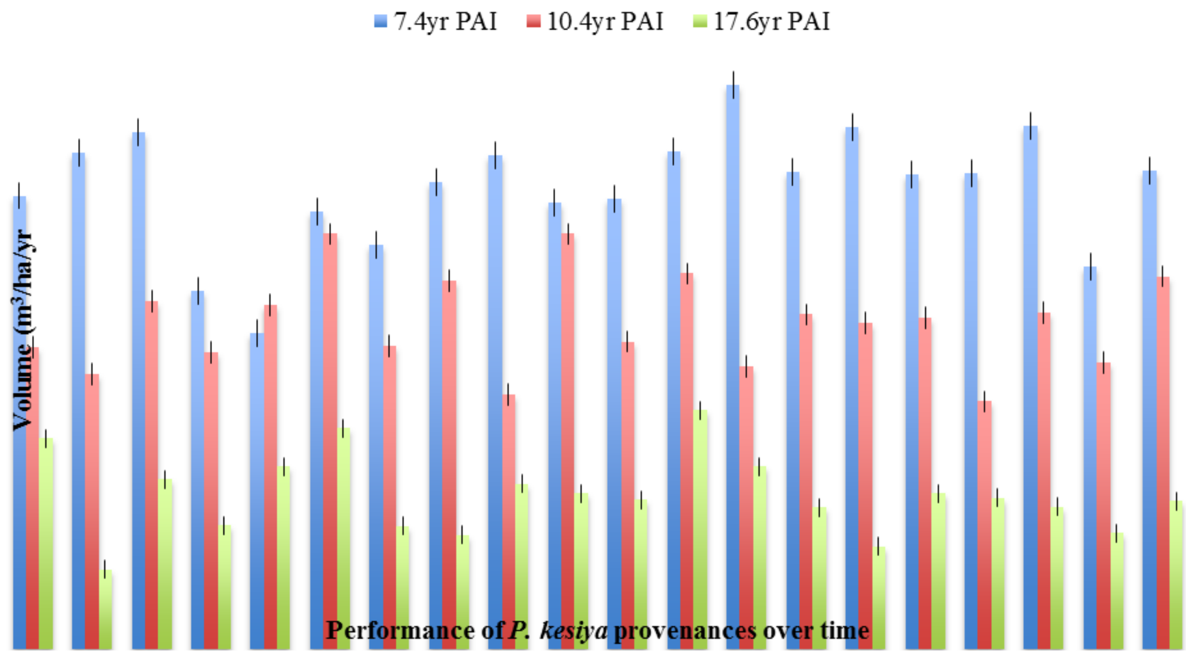

Figure 2. Periodic annual increment of volume of *P. kesiya* provenances in Nzoia, Kenya

Discussion

The study generally showed highly significant differences among *P. kesiya* provenances in survival and growth performance. This variation is vital for any breeding program at inception as researchers gain access to information on best performing provenances (Johnson *et al*., 2001), hence the importance of this study. There was high survival rate for most of the *P. kesiya* provenances at the Nzoia site for the first 2.8 years, ranging between 60 and 95 %, indicative of good climatic and edaphic factors observed within this period of growth. This contrasted observations made at Turbo site, where, by six months, most of the *P. kesiya* provenances and other pines in the study had been destroyed by rats, followed by heavy mortality within the year. The results suggest that the Turbo site was not conducive for *P. kesiya* production. The Nzoia site showed a drastic decline in total mean survival rates over time for all provenances from 71 % at age 2.8 years to 38 % by 17.6 years. Provenances like PK 9269 (Zambeles) and Chichele showed consistently good survival rates over time, indicating that they were adapted to the Nzoia site, which has very shallow soils that are moderately acid and deficient in Ca and P. The Chati provenance ranked third in survival rates above 50% throughout the entire study period, and had high volume growth, suggesting its economic value. Low survival was recorded for PK 9262 (Benquet - Lapanto) and 9265 (Neuva Ecija) of less than 25 % throughout the study period, while PK 9261 (Benquet - Kabeyan) initially had high survival, but there was drastic decline after 5 years, indicating that these provenances may have low adaptability to Nzoia site.

The best height was observed for PK 9263 (Neuva Viscaya) followed by PK 9269 (Zambeles) throughout the study period suggesting that they would be good candidates both for pulpwood and timber if the DBH was also high. Chati, on the other hand, showed a high mean height at age 17.6 years indicative of its potential for timber production. These results concur with that reported for *P. kesiya* provenances, where the Zambales provenance from Philippines showed the highest mean at 18.8 m followed closely by Chati (Chamshama *et al*., 1999). This indicates that these two provenances generally perform well over a wide range of sites. Mean height for *P. kesiya* provenances in our study showed lower means compared to *P. patula* subspp. *tecunumanii* and *P. oocarpa* in the same region where mean heights ranged between 12 m and 15 m at age 8 years, respectively (Kariuki 1998). In addition, similar *P. kesiya* provenances grown in Tanzania (Chamshama *et al*., 1999) showed much better performance in height for all provenances over time compared to our study, which may be due to the poor soils in Nzoia site that are not suitable for most pine species except *P. kesiya* as demonstrated in this study.

Due to poor soils at Nzoia site, it was initially expected that the *P. kesiya* provenances tested would attain a minimum DBH of 10 cm at age 12 years. However, the results surpassed the expectations where DBH of all provenances at age 7.4 years was above 13 cm, which is adequate for pulpwood production (Jones, 2016). The Chati provenance showed the best DBH between 5 and 10 years, of 12 and 22 cm, which suggests that it has potential for pulpwood production, while at 17.6 years PK 9267 (Neuva Ecija - Mt. Benbeu), PK 9265 (Neuva Ecija - Mt. Otang), PK 9261 (Benguet - Lapanto) and Samya showed high DBH above 27.5 cm indicating suitability for timber production. Performance in DBH for *P. kesiya* from Zambia and Philippines was comparable, indicating that Nzoia site was suited for their production. Values observed for *P. kesiya* DBH were comparable to a previous study on *P. patula* subsp. *tecunumanii* and *P. oocarpa* (Kariuki, 1998), indicating that *P. kesiya* could be used as an alternative species for pulpwood production in this area.

High volumes were recorded with the Chati provenance ranking highest at ages between 5.6 and 10.4 years of 8.2 to 29.6 m^3/ha/yr, respectively, which was indicative of good performance in terms of yield at Nzoia site despite the poor soil conditions. At age 7.4 years, the best provenance had a volume of 18 m^3/ha/yr, which was much lower than a study on *P. oocarpa* and *P. patula* with volumes of 25 to 45 m^3/ha/yr at approximately the same age on a similar site (Kariuki, 1998). At age 17 years, PK 9267 (Neuva Ecija - Tilasacana) and PK 9261 (Benquet - Lapanto) ranked highest with 46 m^3/ha/yr. These two provenances could be candidate provenances for timber production. However, the Chichele provenance performed poorly in volume over time indicating that it may not be of economic value when compared to other better performing provenances in the study.

High variability in MAI was recorded in the study, which was in line with productivity of forest plantations which have been documented to range from 1-2 m^3/ha/yr for short-term and 25-30 m^3/ha/yr for medium-term rotation lengths (FAO, 2001). The MAI for volume ranked between 0.8 and 2.9 m^3/ha/yr and PAI 0.8 and 6.2m^3/ha/yr over time, which was low compared to *P. kesiya* provenances in Zambia that ranged between 15 and 40 m^3/ha/yr at age 18 years (Louppe *et al*., 2008) and for softwoods in general of 50 m^3/ha/yr at ages 15 to 17 years (West, 2015). Variability in performance has been attributed to behaviour of the species, site quality, source of genetic material, age of plantation and silvicultural management (FAO, 2001). Low performance of *P. kesiya* provenances in this study was most probably indicative of the poor soils and adaptability to Nzoia site.

Chati and PK 9263 (Neuva vascaya - Kayapa) provenances showed good performance for DBH and volume up to 10.4 years, while at 17.6 years, they both showed good performance in height with Chati having a survival rate above 59% throughout the study period, while PK 9263 was above 40%. This suggests that they are moderately adapted to the Nzoia site and of potential economic importance mostly for pulpwood production. The Zambeles provenance (PK 9269) showed good performance throughout the study period for all the parameters, in addition to good survival indicating that it was adapted to Nzoia site. PK 9267 (Nuevo Ecija) and PK 9261 (Benguet) showed highest volume at 17.6 years, but the survival was low in comparison to other provenances indicating that it could be exploited and improved further in a breeding program. The Chichele provenance showed poor performance for most growth parameters, but survival rates were consistently high, indicating that it was adapted to Nzoia site and its genetic superiority should be explored in breeding programs. Chati provenance showed good performance until 10 years, in addition to a consistently high survival throughout the study period, thus it could be considered for pulpwood production and its genetic superiority on adaptation to the site with poor soils should be explored further through breeding programs.

Conclusion and Recommendations

The study showed high variation in growth performance among provenances PK 9267 (Neuva Ecija) and PK 9261 (Benguet) having potential for timber production and Chati and PK 9269 (Zambeles) for pulpwood production on the poor soils. Other provenances such as Chichele and Chati should be used as good sources of genetic material for breeding programs due to their high survival abilities.

The high significant differences in performance of the *P. kesiya* provenances in the study, was evident of genetic variation among provenances, indicating the potential gains from a tree breeding program of the species. However, there were no differences in performance among provenances from natural populations in the Philippines and those from Zambia ex-Philippines, thus any of these materials could be used in breeding programs depending on performance.

Provenances such as Chichele, Chati, PK 9267 and PK 9269 could be exploited through breeding programs as parental material for different uses.

Due to its ability to thrive in areas with poor soils, *P. kesiya* should be considered as a potential species for sites with poor soil conditions where other species would not survive in the quest to increase forest cover of the country and a contribute towards climate change mitigation.

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The Potential of *Casuarina equisetifolia* L. and *Melia volkensii* Gürke in Improving Soil Fertility in Kwale and Kilifi Counties, Kenya

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Abstract

Low soil fertility is a major biophysical root-cause of declining per capita land productivity in Kenya. In most parts of the country, soils are deficient in nitrogen, phosphorus and in some cases potassium. Trees are important in soil fertility enhancement as they offer an excellent opportunity for farmers to meet nutrient demand in agricultural systems. The aim of the study was to determine the potential of *Casuarina equisetifolia* and *Melia volkensii* on soil fertility improvement in Kwale and Kilifi Counties, Kenya. The experiment was established on-farm in a randomized complete block design with three treatments: Casuarina, Melia and control, eight replicates and 20 x 20 m tree plots. Soil samples were obtained in 2013, 2014, 2015 and 2016 from depths of 0 to 20 cm, 20 to 40 cm and 40 to 60 cm and analyzed for: Soil moisture, soil texture, pH, Electro Conductivity; soil Carbon (C), total nitrogen (N), available phosphorus (P); Potassium (K), Calcium (Ca) and Magnesium (Mg). Data was subjected to Analysis of Variance. Results indicated that total N was higher in *C. equisetifolia* and *M. volkensii* plots compared to the control treatment; and total Carbon ranged from 0.19 % to 1.26 %, while P was highest in *C. equisetifolia* and *M. volkensii* plots. There was a positive correlation between soil pH and soil P (r^2=0.1777 and 0.3201) in 2015 and 2016 respectively. The results indicated that *C. equisetifolia* and *M. volkensii* enhanced soil fertility, which can be attributed to nitrogen fixation by Casuarina through Frankia bacteria and nutrient cycling by Melia. The results of this study are essential for advising farmers engaged in *C. equisetifolia* and *M. volkensii* farming and for promotion of agroforestry using these tree species.

Key words: Soil fertility, Woodlots, Agroforestry, Casuarina, Melia

Introduction

Low soil fertility is a major factor limiting farm productivity in Kenya. In most parts of the country, soils are often deficient in nitrogen (N), phosphorus (P) and in some cases potassium (K). Nitrogen is known to be the most limiting nutrient in most farming systems, since it is required by plants in large quantities. Low soil fertility has in many cases been as a result of nutrient depletion over time due to continuous cultivation and inadequate replenishment of soil nutrients. Soil nutrient depletion is considered the most severe bio-physical root cause of declining per capita food production in Sub-Saharan Africa (Drechsel *et al.*, 2001). Nutrient depletion in soils adversely affects soil quality and reduces crop yield, and consequently poses a potential threat to global food security and agricultural sustainability (Tan *et al*., 2005).

The main factors contributing to nutrient depletion are losses of N and P through soil erosion by wind, water, crop harvest and leaching. Nutrient losses specifically due to erosion in soils in Africa have been reported to range from 10 to 45 kg of NPK per hectare per year (Muriu *et al*., 2005, Julio and Carlos, 2006). Declining soil fertility in Kenya has led to reduced land productivity, thus land users are being encouraged to adopt soil improvement technologies (Muriu *et al*., 2005). Nutrient gains in soils in Africa are mainly through mineral fertilizer application, organic matter mineralization, nutrient deposition by precipitation and Biological Nitrogen Fixation (BNF). Biological Nitrogen Fixation is essential as it offers an excellent opportunity for drawing upon the vast reserve of atmospheric nitrogen in an inexpensive and environmentally sound manner (ICRAF, 2014). The introduction of nitrogen-fixing and highly mycotrophic plant species is a promising way to increase soil fertility. Among nitrogen fixing species, exotic trees such as *Casuarina equisetifolia* are widespread in tropical and sub-tropical zones. These species play an important role in symbiotic relationships with mycorrhizal fungi and Frankia bacteria. These microorganisms increase plant growth and development and also improve nutrient availability particularly N and P for the plant host, which in return benefit from plant carbohydrates (Kandioura *et al*., 2013).

Over two million hectares of *C. equisetifolia* plantations throughout the tropics provide several socio-economic, environmental and ecological services. Their fast growth, adaptability to a range of edaphic and climatic conditions, multiple end uses and the symbiotic nitrogen fixing ability, make them a highly preferred group of trees for farmers (Diagne *et al*., 2013). *Casuarina equisetifolia* plays a crucial role in improving soil fertility, as it is able to grow in nitrogen deficient soils, where other plants may not thrive. The amount of N fixed by actinorhizal trees is comparable to that fixed by legumes and their rhizobium symbionts, and can significantly contribute to N-economy of ecosystems (Kondioura *et al*., 2013). The use of *C. equisetifolia* as a means of replenishing N in the soil has been explored in other parts of the world due to its nitrogen fixing capability (Santi et al., 2013). However, the amount of nutrients made available for crop uptake and its potential to increase crop yields in an agroforestry system and in pure stands after harvesting the trees is not known.

One of Kenya's indigenous species, *Melia volkensii*, is also believed to improve soil fertility and crop yields in agroforestry systems through nutrient recycling (Juma, 2003). Studies however show contrasting results on its ability to increase crop yields through soil fertility enhancement. Studies conducted in Machakos show that crop yields under *M. volkensii* agroforestry system were significantly depressed (Rao *et al*., 1998); while reports by Mulatya *et al*. (2002), indicate that *M. volkensii* increased maize yields and attributed this to effective NPK cycling by the species.

The coastal region of Kenya, where both *C. equisetifolia* and *M. volkensii* are grown is often characterized by poor soils, which have contributed to low agricultural productivity leading to perennial food shortages (Mwangi *et al*., 2010). Farmers in this region often grow maize, which is highly vulnerable to harsh agro-ecological conditions, thus leading to massive losses. Farmers have in the recent past started practicing agroforestry using *C. equisetifolia* and *M. volkensii*. However, information on the potential of both *C. equisetifolia* and *M. volkensii* in improving soil fertility in Kenya is inadequate. This research aimed at evaluating the potential of *C. equisetifolia* and *M. volkensii* in improving soil fertility in Kwale and Kilifi Counties, Kenya.

Materials and Methods

Study sites

The study was conducted in Kwale and Kilifi counties in Kenya (Figure 1). Kwale County has a total population of 649,931people and covers an area of 8,270.2 km^2 (KNBS, 2010). The population density is 79 per km^2 with 74.9 % of the population living below the poverty line. Kwale County has four major topographical features namely the coastal plain; the foot plateau, the coastal uplands and the Nyika plateau. It has a monsoon type of climate; hot and dry from January to April, while June to August is the coolest period of the year. Kwale County receives bimodal type of rainfall with short rains from October to December, and the long rains from April to June or July. The average temperature of the County is 24.2 ^oC and rainfall ranges between 400mm and 1,680 mm per annum. Key agricultural activities and industries pertain to fruit farming, where the main agricultural products are oranges, pawpaws, mangoes, and coconuts. Mixed farming is practiced throughout the county, and it is estimated that 22 % of the region's income is derived from cash crop farming (CRA, 2014).

Kilifi County covers an area of 12,245.90 km^2. The topography of the County is dominated by low-range sand-stone hills, and a terrain that generally slopes towards the sea. The county has 21 forests, cumulatively covering 246 km^2. The average annual rainfall ranges from 300mm in the hinterland parts of the County to 1,300 mm along the coastal belt. Based on the 2009 Kenya Population and Housing Census, the county had about 200,000 households and a population of 1,109,735, which accounted for 2.9 percent of the total Kenyan population (KNBS, 2010). The average precipitation of 900 mm and mean annual temperature of 27 °C hold great potential for agricultural development. Horticultural crops and vegetables such as chilies, brinjals, okra, onions and tomatoes can be cultivated along the Coastal plains. Staple food crops such as maize, rice, bananas, cow peas, green grams and beans also have potential (CRA, 2014).

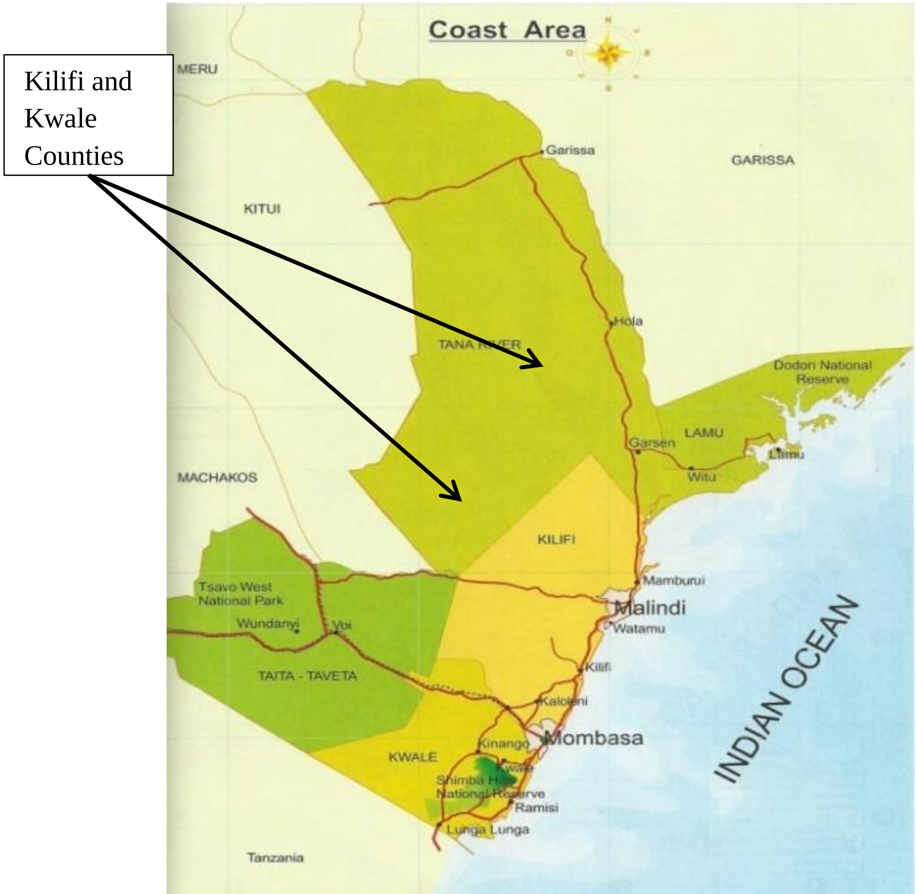

Figure 1. Map showing Kwale and Kilifi Counties in Coastal Kenya

Experimental design and Layout

The experiment was set in a Randomized Complete Block Design (RCBD) with eight replicates for each treatment, and 20 x 20 m tree plots were established in 2013. The treatments were as follows: Control, which was under maize crop, Casuarina planted with crops, and Melia planted with crops.

Soil sampling

Baseline soil characterization was undertaken in 2013 with subsequent soil sampling conducted in 2014, 2015 and 2016 following the Y sampling frame using a soil auger. Four sampling points were randomly selected per plot and samples for each depth thoroughly mixed to form a composite sample. Soil samples were collected from depths of 0 to 20 cm, 20 to 40 cm and 40 to 60 cm. The soil samples were stored in zip-lock bags to prevent contamination and further changes. Core samples were also obtained at the onset of the study for bulk density determination.

Soil analysis

The soil samples were air dried for 24 hour and pulverized to achieve homogeneity. The soil samples were then sieved with a 2 mm sieve to obtain a fine sample. Each soil sample was then divided into four equal parts from which diagonal parts were retained and the other two parts removed, referred to as quartering. This process was done several times until the successive quartering reduced the weight of the composite sample to 0.25 kg. The samples were then placed in zip-lock bags with clear identification. Soil samples were analyzed for the following components using standard analysis procedures: Soil moisture was determine gravimetrically; soil texture was by improved hydrometer method for soil particle size analyses; pH and Electro Conductivity values with glass electrode; total nitrogen was by kjeldahl method; available phosphorus by UV spectrophotometer method; and Potassium, Calcium and Magnesium were determined using Atomic Absorption Spectrophotometer (Okalebo *et al*., 2002).

Data analysis

Data was analyzed through Analysis of Variance (ANOVA) using GenStat (Version 16.0 for windows) at 95 % confidence level. Means were separated using the Least Significant Difference (LSD) test. Other statistical tests: mean and standard error, were conducted using Microsoft Excel.

Results and discussion

Baseline soil status

Table (1) shows the baseline soil status at the onset of the study in February 2013. For both sites, the baseline data shows that the soil in the study sites was deficient in Nitrogen (<0.09 %) and had moderate soil Carbon (<1.17 %). The soil pH ranged from slightly acidic to slightly alkaline (6.97 to 7.07) with low Electrical Conductivity (<0.03 mS/cm). The EC of soil is influenced by the concentration and composition of dissolved salts. Salts increase the ability of a solution to conduct an electrical current, so a high EC value indicates a high salinity level. Generally an EC <0.15 mS/cm will not affect plant growth (Apal, 2013). The available P concentration was low (<2.74 ppm) with moderate Potassium concentration (< 228.05 ppm). The soil had a mean bulk density of 1.34 g/cm^3, an indication that the soils were not compacted. Soil moisture content at the onset of the project was low (<5.4 %).

Table 1. Baseline soil status in Kwale and Kilifi Counties

Site	**pH**	**E.C mS/cm**	**% C**	**% N**	**P (ppm)**	**K (ppm)**	**BD (g/cm^3)**
Kwale	7.1	0.08	0.85	0.08	2.74	228.1	1.33
Kilifi	6.9	0.03	1.17	0.09	1.11	132.1	1.34

Effect of *C. equisetifolia* and *M. volkensii* on soil Phosphorus and Potassium

Figure 2 shows the concentration of P on plots under *C. equisetifolia* and *M. volkensii* at different sampling periods and depth. The concentration of P decreased with depth along the soil profile. This can be attributed to P immobility in the soil. The diffusion rate of P to the root zone is about $^{1}/_{8}$ of an inch per year (Penstate Extension, 2013). *Casuarina equisetifolia* and *M. volkensii* woodlots recorded the highest concentration of soil P (Fig. 2). There was gradual increase of P from the 2013 to 2016, and concentration available increased with increasing age of the woodlots. *Casuarina equisetifolia* forms symbiotic relationship with mycorrhiza fungi that enhances P availability in the soil (Wielderholt and Johnson, 2005 and Kandioura *et al*., 2013). Plots under *Melia volkensii* recorded the highest P concentration (Figure 2). This can be attributed to nutrient cycling by *M. volkensii* (Wielderholt and Johnson, 2005).

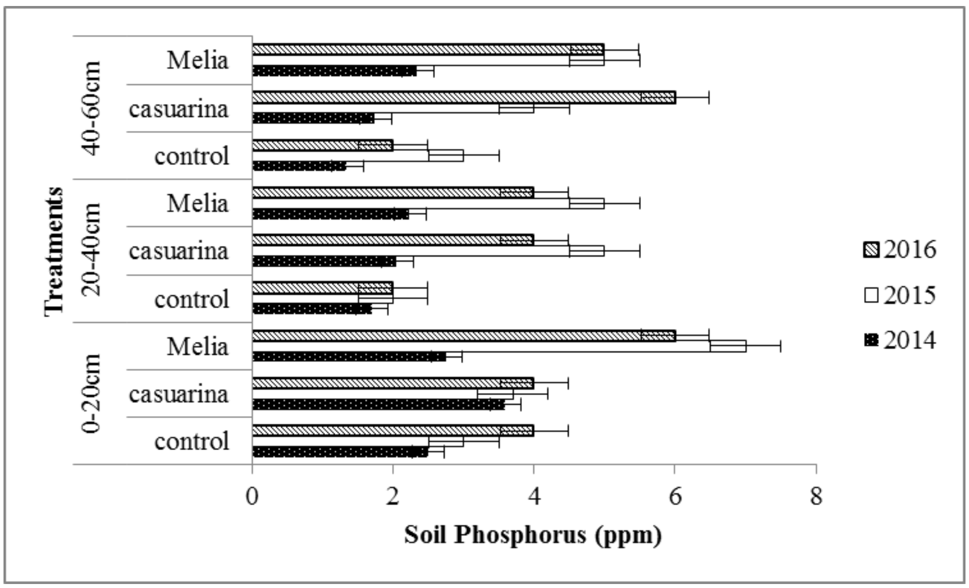

Figure 2. Soil Phosphorus under *C. equisetifolia* and *M. volkensii* at different sampling periods and depth

Generally P was low in all treatments (<11 ppm). This can be attributed to high soil pH. The form and availability of soil phosphorus is noted to be highly pH dependent and P is most available at a pH of about 6.5 with moist and warm conditions. The soils samples used in the study had pH above the optimal range of 6.5. There was a positive correlation between soil pH and soil P across all treatments as illustrated in figures 3 and 4 (r^2=0.1777 and 0.3201 respectively). The increase in soil P was optimum at pH range of 6 to 7 (Fig. 3 and 4).

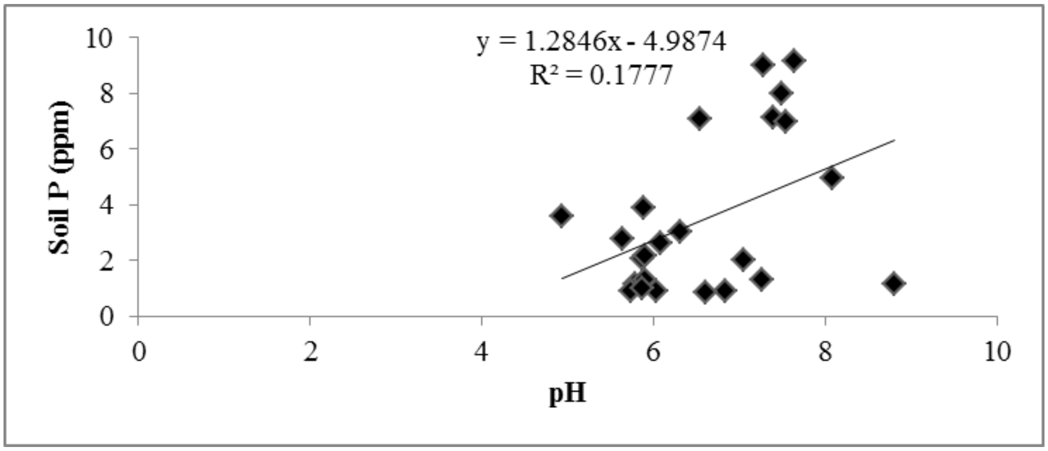

Figure 3. Correlation between soil pH and soil Phosphorus in 2015 at 0 to 20 cm sampling depth, in Kenya

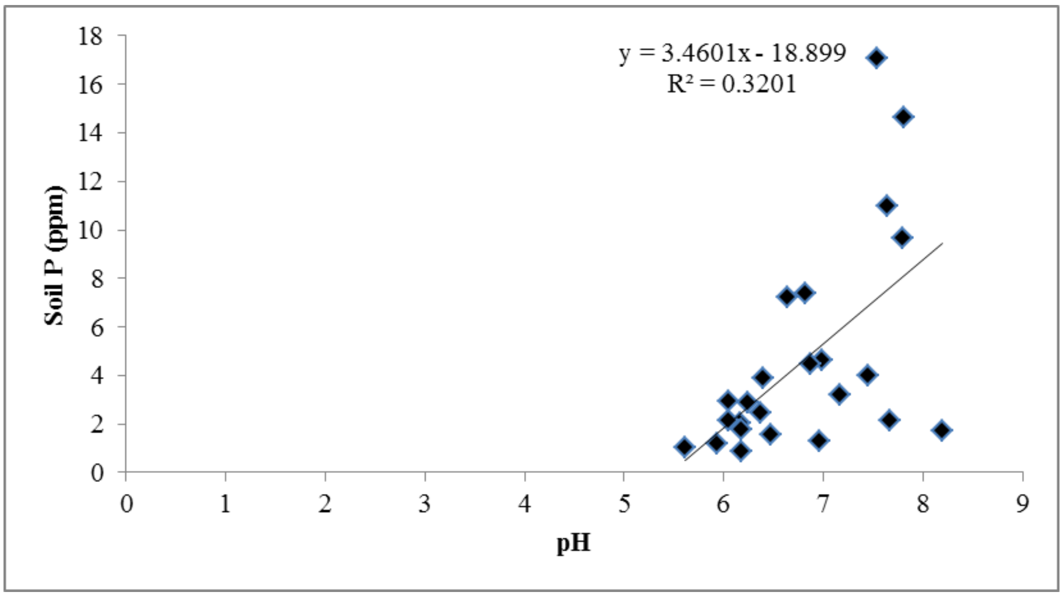

Figure 4. Correlation between soil pH and soil Phosphorus in 2016 at 0 to 20 cm sampling depth

Phosphorus availability has been reported to increase in slightly acidic soils (NRCS, 2015). The limited solubility of P relates to its tendency to form a wide range of stable minerals in soil (McKenzie, 2003).This maximum solubility and plant availability of P at pH 6.5, declines as the pH increases into the alkaline range. This effect of reduced P availability in alkaline soil is driven by the reaction of P with calcium, with the lowest solubility of these calcium phosphate minerals at about pH 8. The presence of lime in alkaline soil further reduces P availability. The lime in calcareous soil reacts with soil solution P to form a strong calcium phosphate bond at the surface of the lime. These alkaline and calcareous soils are common in arid and semi-arid regions where there is little rainfall (Hopkins and Ellsworth, 2005).

Potassium concentration was moderately high across all the treatments (Fig 5). Potassium has been reported to be less limiting in most of the farming systems (McKenzie, 2003). Potassium concentration increased gradually in plots under Casuarina compared to the Melia plots and control treatments, which recorded constant values in 2014, 2015 and 2016. The gradual increase in K in Casuarina plots could be attributed to increase in litter fall under the canopies of *C. equisetifolia* (Belsky *et al*. 1989). The concentration was however higher in soils under *M. volkensii* and this could be attributed to the ability of *M. volkensii* to recycle nutrients from deeper soil layers (Mulatya *et al*., 2002). Similar studies by Belsky *et al*. (1989) have shown that various soil fertility indices such as mineralizable N, extractable P, K, Ca, and soil microbial biomass were elevated in soils under various tree species (Cardelús et al., 2009) . The fixation of K and entrapment at specific sites between clay layers tends to be lower under acid conditions. The high soil pH could have contributed to the moderate soil K at the study sites. This situation may be due to the presence of soluble aluminum that occupies the binding sites. Liming increases K availability, likely through the displacement of exchangeable K by Ca (McKenzie, 2003).

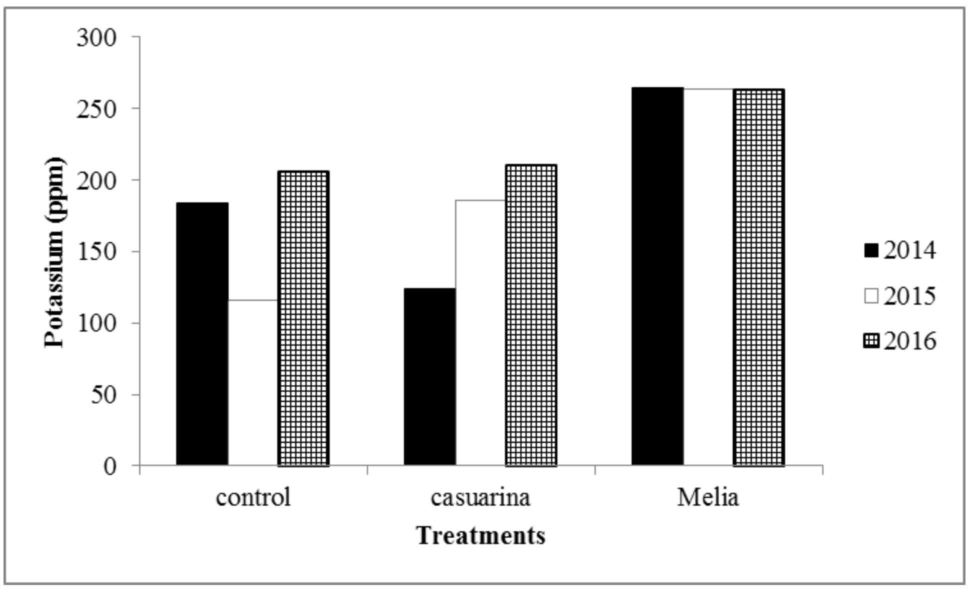

Figure 5. Soil Potassium under *M. volkensii* and *C. equisetifolia* at different sampling periods and depth

Effect of *C. equisetifolia* and *M. volkensii* on soil Nitrogen and Carbon

Total nitrogen increased gradually in the plots under *C. equisetifolia* and *M. volkensii* during the sampling period (Figure 6). The concentration of N however, gradually declined along the soil profile from 0cm to 40 cm, but increased in the 40 to 60 cm sampling depth. This could be attributed to the availability of soil organic matter in the topsoil, which is mineralized by soil microorganisms to release N (Belsky *et al*., 1989). The elevated total N at 40 to 60 cm sampling depth can be attributed to the leaching of soil N to deeper soil layers during the rainy season. Total N was higher in *C. equisetifolia* and *M. volkensii* plots compared to the control treatment.

This could be attributed to the ability of *C. equisetifolia* to fix N through its symbiotic relationship with Frankia bacteria (Nambiar and Brown, 1997, Ye *et al*., 2012) and ability of Melia to cycle nutrients from deep soil layers (Mulatya *et al*., 2002). Studies have shown that *C. equisetifolia* can fix up to 95 kg N per year (Kandioura *et al*., 2013). The genetic make-up of plants, plant age, physical and chemical properties of soil greatly influence the population of Frankia bacteria to fix nitrogen (Pawlowski and Sirrenberg, 2003).

Nitrogen is available in both mineral and organic forms in the soil. Although unavailable to most plants, large amounts of N_2 can be used by leguminous plants through biological N fixation. In this biological process, nodule-forming Rhizobium and Frankia bacteria inhabit the roots of leguminous plants and other nitrogen fixing trees like *C. equisetifolia,* and through a symbiotic relationship convert atmospheric N_2 to a form the plant can use (Ye *et al*., 2012). This could explain the variation of N content across the various treatments in the study.

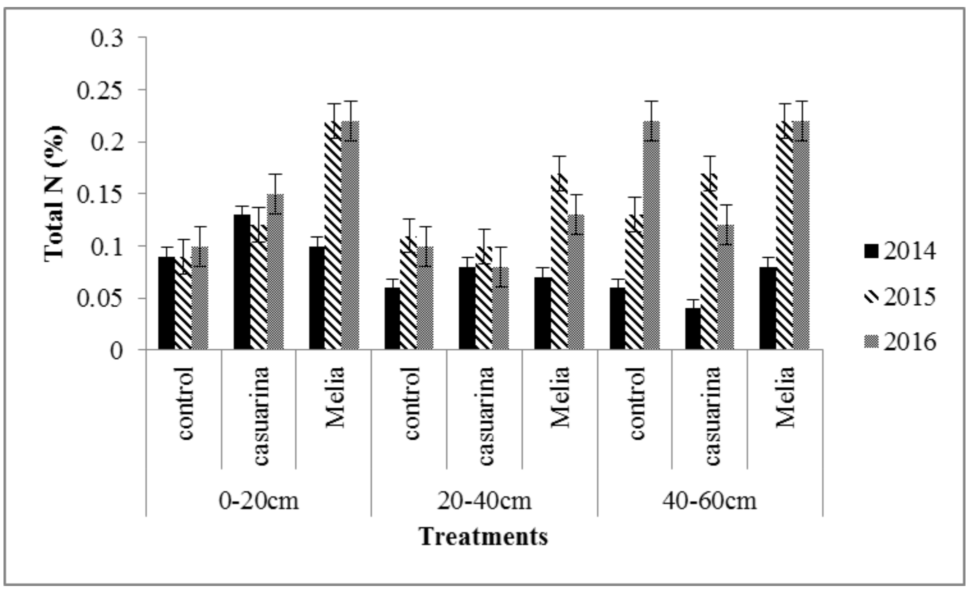

Figure 6. Soil nitrogen under *C. equisetifolia* and *M. volkensii* at different sampling periods and depth

Soil C was low (<1.26 %) and not significantly different across the various treatments (Table 2). However, *C. equisetifolia* plots recorded the highest C content of 1.26 % for top soil and 0.45 % for sub-soil in 2014. Total C however declined in 2015 and 2016 sampling period. This can be attributed to the dry period in 2015 to 2016, which could have hindered decomposition of leaf litter. The concentration of soil carbon declined gradually along the soil profile. According to Horneck *et al*. (2011), the amount of organic matter, which is a determinant of soil C in surface mineral soils, can vary from less than 1 % in coarse-textured, sandy soils to more than 5 % in fertile soils. The amount of organic C in the soil was highest at the A horizon, compared to the lower soil horizons.

The amount of Soil Organic Carbon (SOC) depends on soil texture, climate, vegetation, as well as historical and current land management. Soil texture affects SOC because of the stabilizing properties that clay has on organic matter. Soils with high clay content therefore tend to have higher SOC than soils with low clay content under similar land use and climatic conditions. Climate affects the amount SOC, as it is a major determinant of the rate of decomposition and therefore the turnover time of C in soils (Milne, 2012). Trees add organic matter to the soil system in various ways; in the form of roots, litter fall or as root exudates in the rhizosphere. These additions are the chief substrate for a vast range of organisms involved in soil biological activity and interactions, with important effects on soil nutrients and fertility. Trees contribute to C accumulation in soils, which is stored in various soil horizons (Pinho *et al*., 2012). The ability of soils to accumulate C is generally influenced by texture, where clay soils typically accumulate more C than sandy soils, and some management practices that influence soil C sequestration, particularly the use of trees in agricultural systems (Paudyal, 2003).

The mean C/N ratio across the various treatments was 10. Soil C/N ratio is a sensitive indicator of soil quality, and is often considered as a sign of soil nitrogen mineralization capacity. High soil C/N ratio can slow down the decomposition rate of organic matter and organic nitrogen by limiting the soil microbial activity ability, whereas low soil C/N ratio could accelerate the process of microbial decomposition of organic matter and nitrogen, leading to nutrient release (Shunfeng Ge, 2013).

Table 2. Soil Carbon under *C. equisetifolia* and *M. volkensii* at different sampling periods and depth

Treatment	**0-20 cm**			**20-40 cm**			**40-60 cm**		
	2014	**2015**	**2016**	**2014**	**2015**	**2016**	**2014**	**2015**	**2016**
Control	0.90±0.156[a]	0.37±0.018[a]	0.36±0.054[a]	0.57±0.101[a]	0.26±0.039[a]	0.26±0.044[a]	0.59±0.093[a]	0.20±0.032[a]	0.27±0.028[a]
Casuarina	1.26±0.202[a]	0.28±0.003[a]	0.38±0.074[a]	0.84±0.148[a]	0.23±0.045[a]	0.21±0.066[a]	0.45±0.118[a]	0.19±0.043[a]	0.29±0.042[a]
Melia	1.01±0.184[a]	0.38±0.033[a]	0.39±0.03[a]	0.73±0.124[a]	0.27±0.026[a]	0.26±0.036[a]	0.81±0.117[a]	0.21±0.03[a]	0.28±0.039[a]
	$F(2,23)=1.01$	$F(2,23)=1.48$	$F(2,23)=0.12$	$F(2,23)=1.11$	$F(2,23)=0.23$	$F(2,23)=0.34$	$F(2,23)=2.75$	$F(2,23)=0.16$	$F(2,23)=1.00$
	$p=0.382$	$p=0.249$	$p=0.89$	$p=0.347$	$p=0.793$	$p=0.714$	$p=0.08$	$p=0.852$	$p=0.383$
	LSD =0.534	LSD=0.133	LSD=0.164	LSD=0.370	LSD=0.109	LSD=0.149	LSD=0.323	LSD=0.107	LSD=0.108

Note: *Means denoted by the same letter along the column are not significantly different*

Conclusion and Recommendations

The results indicate that *C. equisetifolia* and *M. volkensii* have potential to improve soil fertility. Plots under *C. equisetifolia* and *M. volkensii* recorded higher nutrient concentration than the control treatment. The lack of significant differences in soil nutrients between *C. equisetifolia* and *M. volkensii* and the control may partly be attributed to the fact that woodlots were only 3 years old, therefore its contribution to soil fertility improvement may not have been fully realized. There is therefore need to undertake the soil assessment under f *C. equisetifolia* and *M. volkensii* or a long period of time to ascertain the trends in nutrient dynamics.

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Compartmentalized Allometric Equation for Estimating Volume and Biomass of *Eucalyptus grandis* in Agroforestry Systems in Kenya

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Abstract

Compartmentalized models to promote sustainable harvesting of on-farm tree parts and estimating carbon stocks are inadequate. This study used a sample of forty-one *Eucalyptus grandis* trees ranging from 4 to 44 cm diameter at breast height. The trees were destructively sampled in Nakuru and Kiambu counties, purposely selected in agro-ecological zone II, III and IV, to collect data on the different compartments namely; stem, roots, branches and stump to develop compartmentalized volume and biomass models. Stem volumes for the whole tree height or to a specific diameter point from the root point were calculated by integrals of splines formed from taper curves of different diameter points. Densities of different compartments of the stem, branches, stump and roots were determined by dividing their sample disks oven dry weight (wood and bark separately) with the fresh volume of the sample disk, whereas, twigs and foliage densities were determined by dividing their sample dry weight with fresh weight. Compartment's biomass was calculated by multiplying their volume with respective density.

Five equations relating volume/biomass of the different compartments to variables including dbh, tree height and crown length were fitted to the data using R -3.3.3 statistical software. The best model was the one with the lowest Akaike Information Criterion values (AIC) and Residual Standard Error (RSE). The findings show that tree height and dbh were the best predictor for volume and biomass of the different compartments.

The developed models are recommended for quantification of compartmentalized products of *E. grandis* and their carbon stocks. The utilized methodology may also be of interest to researchers, planners and academicians.

Introduction

Eucalyptus species were originally introduced in Kenya in 1902 by the colonial government to supply fuelwood for the Kenyan-Uganda railway locomotives (Githiomi *et al*., 2010; Oballa *et al*., 2010). Since their introduction, the genus has dominated various agro-ecological zones due to its fast growth, multiple uses, and suitability to small scale farmers. Furthermore, the species continues to support key sectors of the economy such as manufacturing, construction and energy (KFS, 2009).

Among *Eucalyptus* species found in Kenya, *Eucalyptus grandis* is the most popular species grown. The species is among the fastest growing and grows well in both flooded and well drained soils in wide ranges of altitudes from 0 to 2000 m above sea level (Oballa *et al.*, 2010). Though the species have been grown for a long period in Kenya since its introduction, there is still need of more studies on its allometry, specifically on compartmentalized allometric models that promote sustainable harvesting and estimation of carbon stock of the different parts of the tree.

In a review on registered equations Matieu *et al*, (2011) found Kenya to have only one general equation on *Eucalyptus saligna*, that considered tree biomass in an agroforestry system in western Kenya. Houghton (2001) notes that some developing countries are yet to develop volume and biomass allometric equations for some vegetation types. However, efforts to develop allometric equations for the estimation of volume and biomass have been increasing in the recent years (Chave *et al*., 2005). But there is demand for compartmentalized tree volume and biomass models to promote sustainable harvesting of tree parts while retaining the tree (Hyvonen *et al.*, 2016). With the growing demand for total and sustainable utilization of wood products, it is important for entrepreneurs to be able to estimate the value of different compartments of the tree such as stem, to quantity timber production and the branches for firewood, using reliable variables. Likewise, farmers growing eucalypts and willing to participate in carbon financing would be interested in estimation of the carbon stock in various tree components in order to make informed decisions while participating in the carbon trade.

Given certain parameters, those utilizing *Eucalyptus grandis* would want to estimate the worth of the different compartments of the tree such as stem (quantity of timber), branches (firewood), and roots. For this to be achieved, compartmentalized volume and biomass equations must be developed. None of the past studies on *E. grandis* have developed such models. The objectives for this study were therefore, to develop compartmentalized models for estimating *E. grandis* volume and biomass.

Materials and Methods

Study area

The study was conducted in Nakuru and Kiambu counties of Kenya. In Nakuru County, there were three sites; Molo, Njoro and Rongai whereas in Kiambu County there was only one site, Kikuyu (Figure 1). All the four sites are located in sub-humid and semi-humid Agro-ecological zones of Kenya (Figure 1). Nakuru County has a mean annual temperature of 18 ^{o}C and mean annual rainfall of 1200 mm. Kiambu County has a mean annual temperature of 26 ^{o}C and mean annual rainfall of 2000 mm. All the study sites have deep rich volcanic soils. The main economic activity in both counties is agriculture. Eucalyptus spp. and *Grevillea robusta* are the major agroforestry trees grown in these regions. The trees are distributed in varying development stages, density and management regimes.

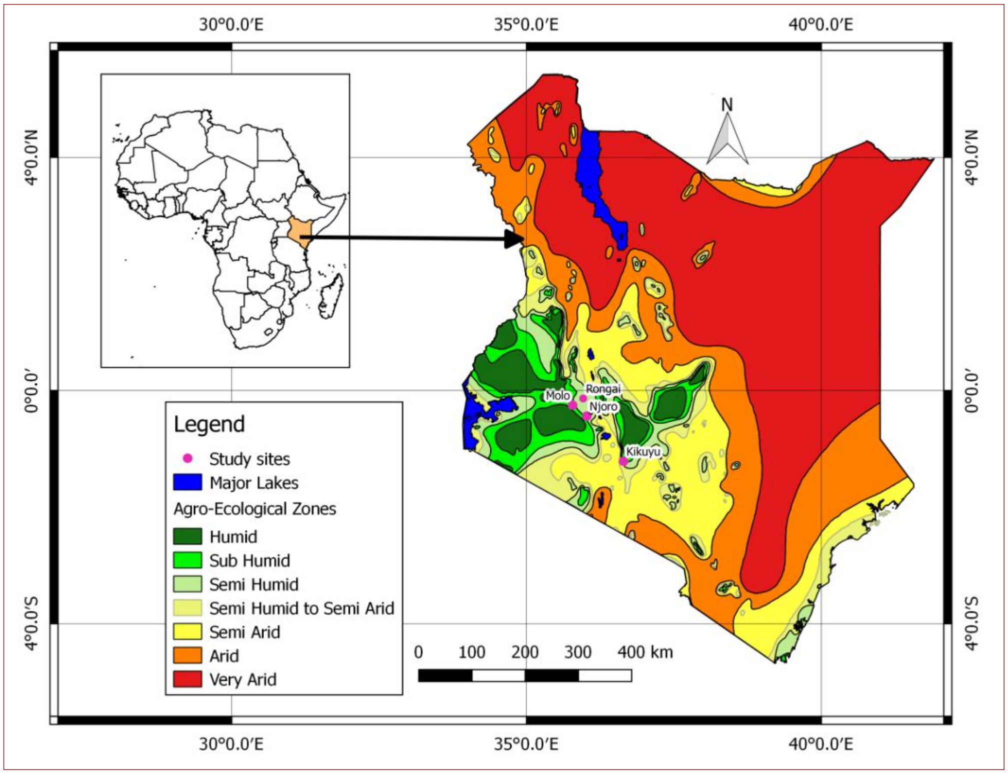

Figure 1. Agro-ecological zones and the locations of the study sites in Kenya

Field measurements and biomass sampling

A total of 41 trees selected across all diameter classes were destructively sampled within the four study sites in line with the recommended protocol (Hyvonen *et al.*, 2016). The dbh of the sample trees ranged from 4.0 cm to 44.0 cm. The following preparatory actions were taken before a tree was felled: digital photograph of the tree, felling direction, tree dbh at 1.3 m above ground using a diameter tape and a point marked by circling the stem with a marker, a point where a tree was planned to be cut (stump height); class of tree crown in relation to other trees, height using a Suunto hypsometer, and height and diameter of the stump. The measurements taken after a tree was felled were: stump height (to nearest 1 cm); stump diameter over-bark (1 mm), stump diameter under-bark (1 mm), under-bark dbh (1 mm); length to the base of living crown (0.01 m); length of living crown in three equal sections; stem length (0.01 m); stem over and under bark diameter (1 mm) at 14 relative heights of 1, 2.5, 5, 7.5, 10, 15, 20, 30, … , 80, and 90% converted to absolute heights in metric scale using the total length of the stem; over-bark diameter of all living primary branches (1 mm) and diameter at least 2 cm.

The living crown of a tree was divided into three sections of equal lengths and from each section, three primary branches: the smallest, average and the largest according to branch diameter (at the base) were selected as sample branch. Thus, each tree had nine sample branches, except for four trees that were considered as 100% sample trees where all branches were sampled. Biomass samples of branch wood were taken by diameter classes (∅); ∅ < 2 cm, 2 ≤ ∅ < 7 cm, 7≤ ∅ < 20 cm and ∅ ≥ 20 cm (Figure 2).

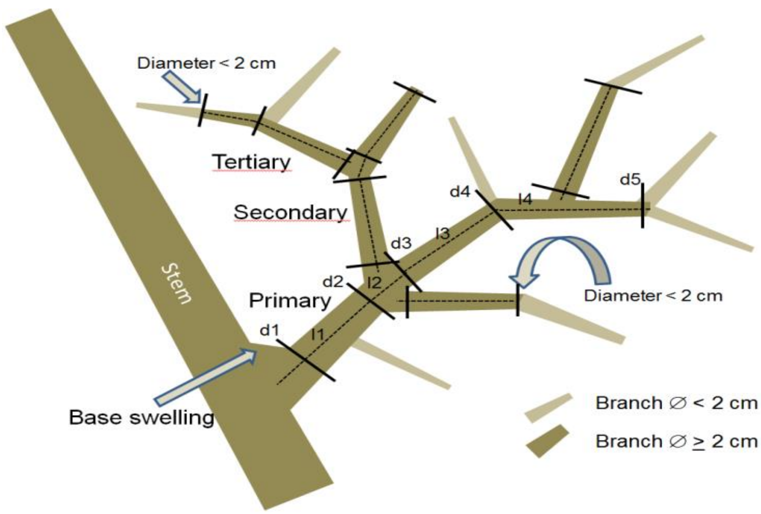

Figure 2. Illustration for measurement of diameter and length of a sample branch

Roots and stumps were excavated using manpower. The soil particles on the surface of both the roots and stump were carefully removed by a sturdy brush before commencing the measurements The data for roots were collected in the same manner as for branches, except that the upper over bark diameter limit was 0.5 cm and only two roots in opposite directions were assessed, and there were no measurements of diameter under bark. For the case of 100% trees all roots were assessed. The sample roots were separated into four size classes (∅): 0.5 < ∅ ≤ 2 cm, 2 ≤ ∅ < 7 cm, 7 ≤ ∅ < 20 cm and ∅ ≥ 20 cm. Fresh weight of samples (0.1 g) from the last three classes were taken using a spring balance. The total fresh weight (100 g) of the stump including the below ground portion after the roots were separated was taken using a spring balance. A vertical segment from the stump (approximately 12.5% or < 1000 g) was extracted and weighed using a digital scale.

The sample of each tree compartment was wrapped in waterproof paper with a tag placed inside and all samples of an individual tree packed in a gunny bag and transported to Kenya Forestry Research Institute (KEFRI) headquarter for laboratory analysis.

Laboratory analysis

The samples of tree compartments analyzed in the laboratory were stem and branch wood, stem and branch bark, dead branches wood, stump wood, roots, twigs, leaves, flowers and pods. Sample wood disks had been extracted from the bottom of the stem, at dbh and at the relative heights of 15%, 50% and 80%. Branch wood samples were obtained from disks or pieces 10-15 cm long of branch size classes $2 \leq \varnothing < 7$ cm, $7 \leq \varnothing < 20$ cm and $\varnothing \geq 20$ cm. The bark samples were obtained from the stem/branch disks and from the branch pieces. The appropriate weight of the fresh laboratory samples was 500–1000 g but could be less if the available materials were not enough. The fresh weights and volumes of stem and branch wood samples with and without bark to accuracy of 0.01 g were determined by water displacement technique using a digital balance that has the ability to tare weight to zero. The weight increment on immersing the wood sample for about five seconds equals the fresh volume of the wood sample. The samples together with their respective bark were wrapped in waterproof paper and a tag placed inside. Samples of stump wood, root wood, twigs, leaves, flowers and pods were treated in a similar manner excluding the bark. The samples were dried in the Kottermann (R) 2713 oven at the temperature of 103^{o}C for 1 to 3 days or when constant dry-weight (0.1 g) was achieved. Samples density (g cm^{-3}) was determined as the ratio of oven dry weight (g) to fresh volume (cm^{-3}).

Data analyses

After the data collection was completed, the data was recorded on excel and imported to R, it was then checked for errors, prior to analysis, and screened for outliers using scatter plots. These scatter plots also revealed the relationship between the volume biomass and predictor variables. Since most of the sampled trees had irregular stems, direct calculation of the volumes from formulae would be inaccurate. Cubic splines were therefore used in volume calculation. With splines, the measurements of tree height and over-bark and under-bark diameters at 14 relative heights of 1, 2.5, 5, 7.5, 10, 15, 20, 30, …, 80, and 90% along the stem were used in calculation of cross cut areas directly. Taper curves for stem volume calculation were formed by a monotone spline according to Fritch and Carson (1980) and calculated with R's splinefun command. This command computes a spline that is increasing or decreasing according to the data, where no values are higher or lower than measured values between measured intervals. They are defined by the use of cubic polynomials on interspaces between diameter points and by continuity of the first and second derivatives in all points of the taper curve. Using this method, stem volumes were calculated by integral of these taper curves. Stem volumes for the whole tree or up to a specific diameter, e.g. 5 cm, were calculated by integral of spline curves from the tree root point.

The volumes of stem barks were calculated as a difference of stem volume with and without bark. The over-and under-bark volumes of sample branches, up to top diameter ≥2 cm, were calculated from the branches' section measurements using the formula of truncated cone (Equation 1) The volume of branch bark were also calculated as the difference of over- and under-bark volumes.

$$V_{branch} = h * \frac{A1 + A2 + \sqrt{A1 * A2}}{3} \qquad \textit{Equation 1}$$

Where; *h* is section length, *A1* area at the base of section, *A2* area at the end of section.

Because not all branches of the trees were measured, a model using the over-bark diameter at the branch base was fitted to estimate branches under-bark wood volume (equation 2, Table 1). A similar model using branch over-bark diameter at the branch base was fitted to estimate the volume of branch bark. The volume of branch with bark will be the sum of under-bark and over-bark volumes.

Table 1. Volume models for *Eucalyptus grandis*

Model	**Model formula**	**Parameter**	**Estimates**	**Standard error of parameter**	**RSE, model**	**AIC, model**
equation 2 n = 220	$V_{branch\_underbark} = a * d^b$	a b	1.335e-8*** 3.065***	2.139e-9 3.245e-2	0.0008725	-3711.491
equation 3 n = 220	$V_{branchbark} = a * d^b$	a b	2.964633e-8** 2.614***	9.169e-9 6.322e-2	0.0000449	-3888.845
Significant codes 0: ***, 0.001: **, 0.01: *, 0.05						

(V = volume in m3, FW = fresh weight in grams, fcp=fruits, cones and pods, d = over bark diameter at the base of the branch in mm, a,b,c are model parameters)

The volume of all branches with a top diameter ≥ 2 cm in a tree were obtained by summing the sample branch volumes (calculated volume) and the estimated volume of the other branches. The above ground volumes of stump (m^3), both over-bark and under-bark were estimated by applying the same truncated cone (frustum) formula as with sample branches (Equation 1). The stump diameter at cutting point multiplied by 1.3 will be used as a stump diameter at ground level. The volume of stump bark will be the difference of over- and under-bark volumes.

The fresh weight of big branches (diameter ≥ 2 cm) and twigs (branch diameter < 2 cm) and foliage (leaves) of the sample branches were used to fit models utilizing branch over bark diameter at the base (Equations 4-1, 4-2, 4-3and 4.4, Table 2) in order to estimate fresh weight of these components for other branches.

Table 2. Fresh weight models for *Eucalyptus grandis*

Model	Model formula	Parameter	Estimates	Standard error of parameter	RSE, model	AIC, model
equation 4-1 n = 235	$FW_{bigbranch} = d\hat{}a$	a	2.129853***	0.006966	356.5	3431.8
equation 4-2 n = 235	$FW_{twigs} = \frac{30{,}000}{1+e^{a*(b-d)}} - c$	a b c	0.01108*** 197.3*** -3453***	0.00.223 11.08 1003	416.5	3506.9
equation 4-3 n = 235	$FW_{foliage} = \frac{1{,}700}{1+e^{a*(b-d)}} - c$	a b c	0.03444*** 9.216*** -9.916*	0.02893 3.854 3.933	353.9	3373.786
equation 4-4 n = 235	$FW_{fcp} = a + b * d$	a b	-286.821*** 77.658***	17.502 4.033	46.14	2471.8

Significant codes 0: ***, 0.001: **, 0.01: *, 0.05: .

(FW = fresh weight in grams, fcp=fruits, cones and pods, d = over bark diameter at the base of the branch in mm, a,b,c are model parameters)

Dependent variables (calculated volume and calculated biomass) were then plotted against several explanatory variables to examine the range and shape of the functional relationship and to assess the heterogeneity of the variance. The following linear models for prediction of volume and biomass were then tested for each of tree compartment.

$$V/B = a * d^b$$

$$V/B = a * d^b * h^c$$

$$V/B = a + d^b + h^c$$

$$V/B = a * d^b * cl^c$$

$$V/B = a + d^b + cl^c$$

Where; V/B: Volume or Biomass, *d*: diameter in cm at breast height; *h*: tree height in m, *cl*: length of living crown in m, and *a*, *b*, *c* are model parameters)

These systems of equations were fitted using "nls" regression in R software for the different tree compartments. The best models were those with the lowest AIC values. The AIC is a way of selecting an equation from a set of (alternative) equations by balancing changes in the goodness-of-fit versus difference in the number of parameters (Kuyah *et al.*, 2013)

Results

Diameter at breast height, crown length and height were effective predictors for the different categories of volumes and biomass. However, some models developed underestimated volume at smaller dbh (Figure 3) e.g.,volume model V.stem3 developed for the stem compartment underestimated volume at dbhs less than 5 cm but had better agreement with V.stem and V.stem2 at intermediate dbhs *Ps*: One observation (point approx. 75, 2) was added manually for estimation purposes.

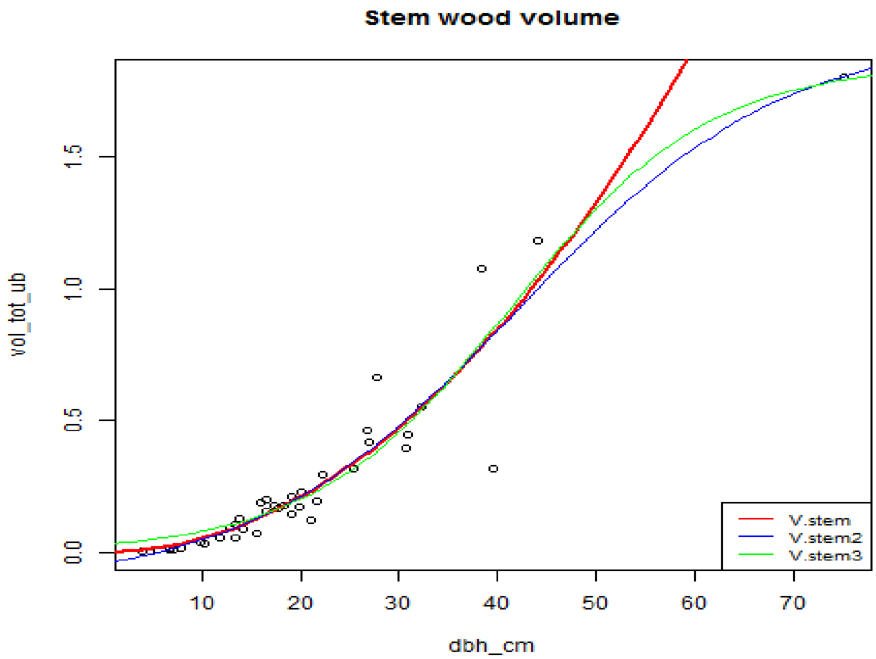

Figure 3. A comparison of volume models developed for stem compartment.

The volume models developed for each compartment and their resulting coefficients and other statistics are shown in Table 3.

Table 3. Parameters and statistics of the best fitted volume models for *Eucalyptus grandis*

Model	**Model formula**	**Parameter**	**Estimates**	**Standard error of parameter**	**RSE, model**	**AIC, model**
Stem wood up to 5 cm top diameter	$V_{stemwood} = a * d^b$	a	0.00046**	0.0003	0.1147	-55.75928
		b	2.03284***	0.1937		
Stem wood, whole tree	$V_{stemwood} = a * d^b$	a	0.00050**	0.00034	0.1148	-55.70913
		b	2.01513***	0.1918		
Stem bark, up to 5 cm top diameter	$V_{stembark} = a * d^b * h^c$	a	0.00005*	0.00002506	0.0069	-280.13
		b	1.434***	0.0860		
		c	0.7943***	0.1658		
Stem bark, whole stem	$V_{stembark} = a * d^b * h^c$	a	0.000050*	0.000024	0.0068	-280.84
		b	1.435***	0.0861		
		c	0.8131***	0.1658		
Branch wood	$V_{branchwood} = a * d^b$	a	1.606e-31	2.039e-30	0.0527	-102.6498
		b	1.870e+01**	3.358		
Branch bark	$V_{branchbark} = a * d^b$	a	2.536e-16	1.474e-15	0.0150	-190.4843
		b	9.004	1.546***		
Stump wood	$V_{stumpwood} = a * d^b$	a	-1.0172***	2.064e-9	0.0038	-328.0125
		b	0.0081***	1.379		
Stump bark	$V_{stumpbark} = a * d^b * h^c$	a	-2.0050999***	5.788e-11	0.0011	-420.11
		b	0.001999**	1.842		
		c	0.0004611	1.954		

Significant codes 0: ***, 0.001: **, 0.01: *, 0.05

(V = volume in m3, d = diameter at dbh in cm, h = height in m, a ,b, c are model parameters) Bolded models represent the best model)

It is clear from the above equations that dbh and height were the best predictors for calculation of volume for the various compartments, all the best equations for the different compartments have either dbh (d) or a combination of dbh (d) and height (h). Biomass equations developed for the various compartments are shown in table 4.

Table 4. Parameters and statistics of the best fitted biomass models for *Eucalyptus grandis*

Model	Model formula	Parameter	Estimates	Standard error of parameter	RSE, model	AIC, model
Stem wood, whole stem	$B_{stemwood} = a * d^b * cl^c$	a	0.09133*	0.06115	19.32	432.2517
		b	1.58749***	0.21333		
		c	1.00656*	0.27375		
Stem bark	$B_{stembark} = a * d^b$	a	0.009788	0.012082	21.55	363.08
		b	2.53748***	0,343383		
Branch wood, diameter >=2 cm	$B_{branchwood} = a * d^b * cl^c$	a	0.1025	0.2424	30.79	324.69
		b	1.1005*	0.467		
		c	1.0196	0.8164		
Branch bark	$B_{branchbark} = a * d^b$	a	0.0963	0.3552	34.1	330.45
		b	1.6165	1.0604		
Twigs, diameter < 2cm	$B_{twig} = a + d^b + cl^c$	a	0.00425	2.2894	5.475	229.44
		b	2.5620***	0.0666		
		c	-0.54641	0.1778		
Foliage	$B_{foliage} = a + d^b + cl^c$	a	-4.8745*	2.0931	5.844	234.15
		b	0.5867***	0.1413		
		c	0.4041.	0.2034		
Stump wood	$B_{stumpwood} = a + d^b + cl^c$	a	-4.41171***	0.51671	1.456	144.86
		b	0.57208***	0.06009		
		c	0.16086.	0.08638		
Stump bark	$B_{stumpbark} = a + d^b$	a	-2.53009**	0.81313	1.925	165.69
		b	0.41595***	0.08001		
Aboveground, all	$B_{aboveground} = a * d^b * cl^c$	a	0.224	0.1657	68.93	457.05
		b	1.7238***	0.1639		
		c	0.6251*	0.2541		
Roots	$B_{root} = a * d^b * cl^c$	a	-6.19625	1.11757	0.6617	10.5
		b	059671.	0.04719		

		c	0.51299	0.09094		
Stump, belowground	$B_{stumpbg} = a * d^b * cl^c$	a	-9.93054	3.04654		19.49
		b	0.80755.	0.08547	2.035	
		c	0.51075	0.17109		
Belowground, all	$\ln(B_{belowground}) = a * d^b * cl^c$	a	0.50209.	0.07691	0.07622	-6.79
		b	0.40363.	0.03466	1.0785 [1]	
		c	0.35964	0.06133		

[1] RSE calculated with estimated real values (not from model's residuals which are in logarithmic scale)
Significant codes 0: ***, 0.001: **, 0.01: *, 0.05: .

(B = biomass in kg, d = diameter at dbh in cm, h = height/length in m, cl = crown length in m, ln = natural logarithm, and a, b, c are model parameters).

Discussion

Nonlinear models were fitted for volume and biomass estimation for each tree component. The difference between the performance of linear and non-linear models for tree components has been noted to be negligible (Magalhães *et al.*, 2015), however Salis *et al.*, 2006 and Schroeder *et al.*, 1997 found nonlinear models to perform better than linear models, their findings therefore informed this works analysis.

The volume equations developed for the different compartments of *E. grandis* were functions of dbh alone or a combination of dbh and height. Most parameter estimates were significant at 5% level. All the biomass models developed for the different compartments excluded height as a predictor and used either dbh alone or a combination of dbh and crown length. Crown parameters are generally difficult to measure accurately, nonetheless, our equations show that inclusion of crown length improves the accuracy of the trees biomass (Kuyah *et a1.*, 2012)

The relationships between stem wood and stem bark biomass compartments with dbh were more pronounced than other compartments. The relationships of the other compartments were not pronounced because they are influenced by various management practices applied to the agroforestry trees, which have been reported by Víquez and Perez (2005) and Petersen *et al*., (2008).

Conclusion

Tree height and dbh were the best predictor for volume and biomass of different compartments of *E. grandis*. The developed allometric equations can be used to estimate volume and biomass of the different compartments of *Eucalyptus grandis* in agricultural landscapes in similar agro-ecological zones, provided that tree growth parameters fall within similar ranges to those of the sampled population. The methodology used in data collection can also be of interest to forest managers, researchers and academicians.

Acknowledgement

This study was funded by the Government of Kenya and Government of Finland through the Project Improved capacity for forest resources assessment in Kenya implemented under Miti Mingi Maisha Bora programme. We most sincerely thank Director, Kenya Forestry Research Institute (KEFRI) and Director, Natural Resources Institute, Finland (Luke) for allowing their staff to participate in designing this study, collection, analysis, and interpretation of data and writing the manuscript. The farmers who provided the sample trees, field data collection team led by William Mucheke and Mwangi wa Gathura, and any other person who contributed to this work in one way or another are highly acknowledged.

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Application of Biochar from Sugar Baggase as Organic Soil Amendment Material in Agricultural Production in Homa Bay County, Kenya

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Abstract

Biochar is a solid material obtained from thermo-chemical conversion of biomass in an oxygen-limited environment. Through a carbonization process, biochar produced are mainly used to make briquettes used as a source of green energy. Apart from briquette making, biochar can also be used as a soil amendment material to enhance soil quality and increased water retention that can result in increased crop yields. In order to understand the benefit interactions between biochar from sugarcane bagasse and soil that would lead to improved crop production, field trials were established in Ndhiwa Sub-County in two different sites with contrasting soil characteristics (clay and loamy soils). The trials were conducted during the short rains (September- December 2016 and the long rains of March –May, 2017). The experimental design adopted was a randomized design having four (4) treatments and 3 replicates. The plot size was 5 x 5 m, inter row spacing was 90 cm, intra row spacing for the maize crop was 30 cm, and space between plots and blocks was 1 m. The 4 treatments were: T_1 - Control (No inputs); T_2 – Biochar alone; T_3- Fertilizer alone and T_4 – Fertilizer + Biochar. Inorganic fertilizer, DAP was applied at a rated of 60Kg P_2O_5/ha). While biochar was applied to each planting hole at a rate of 150 g/hole. Germination success was scored at the beginning of the trials and later maize stover production and grain yields were assessed at the end of the season. Plots treated with biochar alone gave a mean grain yield of 1547.88 g, followed by DAP alone at 1161.07 g, then control (no amendments) with 961.08 g and lastly a combination of biochar +DAP at 943.96 g.

Keywords: Biochar, crops, soil amendment, sugarcane baggase

Background

Biochar is the carbon material produced by slowly burning biomass in a restricted flow of oxygen, and then the fire is stopped when the material reaches the charcoal stage through a process called pyrolysis (Downie *et al.*, 2009). Coarse lumps of charcoal biochar are full of crevices and holes, which help them, serve as life rafts to soil microorganisms (Ameloot *et al*., 2013). The carbon compounds in biochar form loose chemical bonds with soluble plant nutrients thereby preventing the adsorbed nutrients from being readily washed away by rain or through irrigation (Atkinson *et al*., 2010). Biochar alone added to poor soil has little benefit to plants, but when used in combination with compost and organic fertilizers, it can dramatically improve plant growth while helping retain nutrients in the soil (de la Rosa and Knicker, 2011).

Through a carbonization process, biochar can be produced from different plant materials or biomass wastes such as sugarcane bagasse produced from sugar factories. Bagasse is the fibrous matter that remains after sugarcane is crushed to extract the juice. Large quantities of biochar dust used for soil amendment is another way to sequester carbon, enhancing soil quality and increasing soil water retention (Koide *et al*,. 2015; Laird 2008; Spokas *et al*., 2012). Carbonizing of bagasse has many environmental and agricultural benefits, including waste reduction on the sugar factories and to substitute wood for energy production.

The use of biochar as a soil amendment is an innovative and highly promising practice for sustainable agriculture and useful for Africa. In agricultural production, application of biochar is anticipated to improve and prolong long term effects on soil physical structure, retains nutrient thereby reducing leaching loss through improved Cation Exchange capacity (CEC) and may aid accumulation of soil organic matter (Spokas *et al*., 2012). Characteristic and quality of biochar depends on several factors such as the origin of organic material used, temperature and the absence of oxygen through the carbonizing process. Too high temperature produces only ash that is of less use. This will determine the density and/ or weight of the biochar produced after carbonization (Downie *et al*., 2009). From other studies, biochar from sugarcane bagasse are relatively lighter than those from wood products and are easy to apply in agricultural fields since large quantities may be required.

There are quite a number of sugar factories within the Kenyan Lake Victoria basin producing bagasse as a by-product from crushed canes. Sukari Industries Limited located in Ndhiwa Sub-County within Homa Bay County is one of such factories. Ndhiwa is one of the eight sub-Counties constituting Homa Bay County and has a population of 172,212 people where majority of the rural households still rely on biomass energy (Homa Bay County CIDP, 2013). They also practice subsistence farming with little or no inorganic fertilizer applications. The Green Economy and Partnership Project (GEP) funded by the Nordic Climate Facility (NCF) and jointly implemented by the Royal Norwegian Society for Development (NorgesVel), the Kenya Forestry Research Institute (KEFRI) and Gum Arabic and Resins Association (GARA) has established community bio-enterprises that produces and supplies carbonized biomass for making briquettes and soil amendments for crop production.

In order to understand the benefit interactions between biochar from sugarcane bagasse and soil that would lead to improved crop production, field trials were established in Ndhiwa Sub-County, Kanyadoto ward in two different sites with contrasting soil characteristics (clay and loamy soils). The trials were initiated during the short rains (September, 2016 to January 2017 between March – July, 2017.

Materials and Method

Site preparation

The trials were established at three sites within Ndhiwa Sub-County in Homa Bay County namely; Amoyo, Bonguand and Ligodho. Amoyo was selected as it has sandy soil; Bongu has clay-loam soil while Ligodho has clay soil. Experimental land was oxen-ploughed before the plots were marked. After marking the plots, soil samples were collected before any treatment was applied. Maize (*Zea mays*) variety SC DUMA 43 which is early maturing was used as the test crop. The rainfall pattern in the area is erratic and can even stop before the crops mature, hence the precaution to plant early maturing maize variety. Generally the rainfall received in the study locations during long rainy season ranges from 250 – 1000 mm while 500 –700 mm is received in the short rainy season. The sites were less than 5 km apart so the amount of rainfall for all the sites was more or less the same. It is important to note that in all the sites there was no irrigation system so communities around solely depend on rain fed agriculture for crop production.

Experimental design and treatment

The experiment was laid out in a randomized block design having 3 blocks, 4 treatments and 3 replicates. The plot size was 5 m x 5 m, where maize (*Zea Mays L*) crop were planted at a spacing of 90 cm x 30 cm through direct seeding with a space between plots measuring 1 m. For optimum growth, maize crop requires fertilizer application of 60 KgN/ha and 60 Kg P_2O_5/ha (Sanchez, 2002). Phosphorus was added at planting in form of DAP (Di-ammonium phosphate). Each planting hole received about 5 g of DAP which was mixed thoroughly with soil before sowing the seeds of maize. The quantity of biochar applied to each planting hole before sowing was 150 g.

Germination assessment

Fourteen days after planting, germination assessment was done where all the germinated seedlings were counted and recorded. The figures generated were used to calculate the percentage germination based on the expected total plant population in each plot.

Crop yield assessment

For crop yield assessment, sampling in the experimental plots were done as follows; outer two lines and outer two crops from both ends of crop lines were left out as guard areas to minimize the edge effects. All the remaining crops in the net plot were counted and then harvested. The maize cobs were separated from the stover. The harvested maize stovers in the net plots were heaped together per plot and their weight recorded. A representative sample of six (6) plants were taken to represent the large, medium and small crops and then chopped into small pieces. The chopped pieces were thoroughly mixed and a sub-sample taken whose fresh weight was also recorded at the site. The sub-samples (stover) were taken to the lab where they were dried at a temperature of 70^{o}C to a constant weight. The dry weights recorded in the lab were used to determine the moisture content and dry biomass yield of the stover. Maize crop and stover sampled were taken to Maseno Regional research centre where they were sun dried, then threshed, thereby separating the grains from the cobs. Grain yield was then determined after taking the sample weights after separating the cobs from the grains.

Results and Discussion

Germination assessment

The sandy soils at Amoyo had generally low germination percentage at 51 % compared to 77 % at Ligodho and 83 % for Bongu sites. The ANOVA showed that germination in the sandy soil was low regardless of the treatment applied. This could be attributed to low soil moisture content in the sandy soils at Amoyo as opposed to high soil moisture content in clay soils at Ligogho and loam soil at Bongu respectively.

Table 1. Mean germination percentage per site as affected by treatments

Treatment	Amoyo	Bongu	Ligodho
Biochar	60	90	89
Control	44	85	72
DAP	36	81	76
DAP+Biochar	62	76	73

Regardless of the site or type of soil, application of biochar recorded high germination at 80 % followed by biochar + DAP at 70 %, then Control at 67 % and lastly DAP alone at 64 %. Since spot application of DAP was done in the planting holes, the low germination in treatments that received DAP could be as a result of scorching effect when the fertilizer came into direct contact with the sown seed.

Stover and grain yield assessment

Due to adverse weather conditions, crops in the sandy soils (Amoyo) did not grow to maturity to produce grains. Most of the plants withered at early stages and therefore, no data was collected for yield determination. Therefore, the yield data is for two sites only, that is Bongu (Clay-loam soil) and Ligodho (Clay soil). Generally, treatments applied significantly affected the maize stover yield but there were no significant variations ($P \leq 0.5$) in site differences (Table 2). The detailed mean values are given in Table 3 below.

Table 2. Analysis of variance table showing variations in stover biomass (Kg) as affected by treatments and site

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	17.8776	5.9592	6.56	0.004
Site	1	3.8711	3.8711	4.26	0.056
Treatment.Site	3	15.6397	5.2132	5.74	0.007
Residual	16	14.5395	0.9087		
Total	23	51.9279			

Table 3. Mean values of stover weight given as treatment, site and grand mean (Kg)

Treatment	**Biochar**	**Control**	**DAP**	**DAP + Biochar**
	5.91	4.7	4.92	6.87
Site	Bongu	Ligodho		
	5.2	6		
Treatment	Site	Bongu	Ligodho	
Biochar		5.85	5.98	
Control		4.57	4.83	
DAP		5.27	4.56	
DAP + Biochar		5.11	8.63	

The grain yield for the net plot sampled after leaving outer lines and two crops from each end of the crop line were assessed. Results indicate that application of biochar alone resulted in significant high yields of maize grain in both sites assessed. Plots treated with biochar alone gave a mean grain yield of 1547.88 g, followed by DAP alone at 1161.07 g, then control (no amendments) with 961.08 g and lastly a combination of biochar +DAP at 943.96 g. Bongu site (clay-loam) produced averagely higher grains per plot (1248.46 g) than Ligodho site (1058.53 g).

Further assessment of 100 grains collected randomly from samples also showed significant differences (Tables 4 and 5).

Table 4. Analysis of variance table for mean weights (g) of 100 grains randomly collected from each sample plot

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatment	3	115.87	38.623	4.8	0.014
Site	1	64.485	64.485	8.01	0.012
Treatment. Site	3	4.968	1.656	0.21	0.891
Residual	16	128.792	8.05		
Total	23	314.115			

Table 5. Mean weight (g) of 100 grains as affected by treatments and site

Treatment	Biochar	Control	DAP	DAP + Biochar
	28.41	22.79	24.25	23.39
Site	Bongu	Ligodho		
	26.35	23.07		
Treatment	Block	Bongu	Ligodho	
Biochar		30.25	26.57	
Control		24.64	20.95	
DAP		26.26	22.24	
DAP and Biochar		24.25	22.53	
Grand mean 24.71				

Conclusions

From the data collected it was evident that biochar application has significant benefits in improving maize crop production. The biomass produced and general yields of maize crop were high in both test fields especially where biochar was added. The yield increase was highest at Bongu with Clay-loamy soil. Probably the effect of water retention capacity was decisive. The bad germination at Amoyo was most probably caused by severe water stress in sandy soils.

Acknowledgement

We sincerely thank the Kenyan and the Norwegian Governments for availing the resource through the Green Economy Partnership Project hosted at KEFRI Karura that enabled us to conduct these trials. Further appreciations go to Mr Fred Amolo, Samuel Kirui and Ms. Joyce Oreta of KEFRI Lake Victoria Basin Eco-region Research Program and the project staff based at Kuja River led by Mr. Amos Odhiambo for data collection and compilation.

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Effect of Moisture Content and Temperature on Viability and Longevity of *Cordia sinensis* Lam. Seeds

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Abstract

There are challenges acquiring viable and vigorous *Cordia sinensis* (L) seeds for raising planting materials due to difficulties in post-harvest storage. In spite of the tree's exceptional multipurpose qualities and ability to grow in arid and semi-arid lands (ASALs), little effort has been put in improving the post-harvest storage of the seeds. The main objective of this study was to determine the effect of different temperatures and moisture contents of *Cordia simesis* seeds on viability, vigour and longevity on storage. Seeds of *Cordia sinenis* were stored in corked glass vials for up to 150 days at different constant temperature ranging from 6 ^{0}C to 35 ^{0}C and moisture contents ranging 6 % to 18 % (fresh weight basis). Seed with different moisture contents were retrieved at intervals of 30 days from different storage temperature regimes for viability tests for a period of 150 days. Viability, vigour and storage period (longevity) decline during storage was generally lower at lower temperatures and moisture contents but rapid at higher temperatures and moisture contents. The estimated periods for viability to fall to 50 % (P_{50} half-life value) decreased with the increase in seed moisture contents and storage temperatures. The viability results obtained could be used to predict the longevity and expected number of seedlings at different times. The results obtained in the present study could be applied in predicting viability loss, vigour and number of seedlings especially under short to medium-term storage conditions.

Keywords: Viability, vigour, longevity, *Cordia, sinensis,* half-life

Introduction

The primary essence of long storage of seeds is to maintain their viability and vigour for the duration they are required. This task is challenging due to deterioration of seeds in storage, which usually leads to decline in vigour and reduced number of viable seeds. Seed quality is known to be affected during pre- and post-harvest period (Walters and Engels, 1998). Quality seeds are collected at the point of natural dispersal to ensure that quality, desiccation tolerance (for orthodox seeds) and longevity are maximized (Hay and Probert, 2000). During collection a good separation distance between the mother trees is also important especially in natural forests, to ensure that one does not collect related half-sibs which ultimately lead to inbreeding of the resultant population. About thirty mother trees with a spacing of about one hundred metres between them is recommended for a majority of species (Dawson and Were, 1998).

Storage is considered as the preservation of viable seeds from the period of collection until they are required for sowing (Holmes and Buszewicz, 1958). The time taken for viability to decline by 50 % (P_{50}-half-life) is widely used as a measure of longevity in many plant species (Probert, 2003; Muthoka, 2000). Seed moisture content and temperature are two critical factors that determine duration of storage (Thomsen, 2000). Vigour and germination of seeds stored at high temperatures or high seed moisture levels decline more rapidly than those stored under cooler and drier conditions (Burris, 1980). Seed deterioration is considered as the increased probability of death of an individual seed as deterioration proceeds (Tang *et al.,* 2000), whilst, seed death is considered as failure to germinate thus seed longevity is considered as the period until seed death occurs (Hay *et al*., 2003; Mollah *et* al., 2002; Sacande *et al*., 2000).

Many tropical forest species produce recalcitrant seeds (Sacande´*et al.*, 2004), including many of the species important for timber. Recalcitrant seeds survive desiccation to relatively high moisture content (often 30 % MC depending on species) and die on storage at sub-zero temperature (Berjak and Pammenter, 2008). Based on seed response to desiccation, seed storage behavior are categorized into three: orthodox, intermediate and recalcitrant. Orthodox seeds can be dried to low water contents (4-7 %) with little effect on viability whilst recalcitrant seeds are killed by drying to moisture contents below 20-30 % (Pritchard, 2004). Research reveals that Intermediate seeds can survive considerable levels of desiccation to levels approaching those of orthodox seeds (MC. 7-10 %), but do not benefit from sub-zero temperatures (Ellis *et al.*, 1990). However, forest species are classified as: true orthodox for those tolerates drying below 10 % moisture content and storage at sub-zero temperatures; recalcitrant tropical (could be stored in high relative humidity, with higher sensitivity to low temperatures and desiccation (Kapoor *et al.*, 2011).

Materials and Methods

Seed collection and processing

The study was conducted between December 2014 and August 2015 at Kenya Forestry Seed Centre in Muguga. Yellow ripe fruits of *Cordia sinensis* were collected from Baringo and Turkana counties in equal quantities for good sample representation (Omondi *et al.,* 2004). The collected fruits were separately carried in sisal, 90 kg sacks from the field to the laboratory at Muguga for processing them separately. The fruits, containing seeds from each provenance were separately sampled by getting a handful representative quantity by dipping hand in the sacks in all sides and middle to get some fruits. Squeezing the fruit and rubbing derived seeds with a dry towel extracted the sampled fruits. The extracted seeds were tested for moisture content by subjecting each sample weighing 5 g to quick monitoring automatic infra-red moisture content machine to guide and allow immediate processing of seed lots and replicate sample subjected to high adjustable automatic temperature oven method (ISTA, 2007). The moisture contents results obtained from quick monitoring automatic infra-red moisture content machine were used as the initial moisture contents of the seed lots awaiting extraction. The remaining fruits were placed on a wire screen/mess and gently rubbed with hand to remove the fresh pulp and reduce sticky mucilage on the seeds. The extracted seeds were washed with water under pressure to remove mucilage (Hong and Ellis, 2004) before gently rubbing with towel to remove excess water on seed surface. A sub-sample was randomly drawn from each experimental lot for confirming moisture contents against initial moisture contents using recommended high adjustable automatic temperature oven method (ISTA, 2007) and for determination of vigour and viability of each sample of the extracted seed lots.

Seed moisture content determination and desiccation process

The high adjustable automatic temperature oven method (ISTA, 2007) was used to determine moisture content both initially and subsequently for extracted seeds during adjustments to respective moisture contents regime. Approximately 5 grams were accurately weighed (to 3 decimal places) in two replicates into dry, clean, pre-weighed petri dishes and placed into a preheated oven at 107 ^{0}C for 17 hours. At the end of each exposure period, the seeds were cooled for 45 minutes inside a desiccator and reweighed.

Moisture content (MC) was expressed on a fresh weight basis. Combination of cool air and silica gel methods was used to adjust moisture contents from the initial levels to the targeted storage levels. In the silica gel drying methods, sub-samples of seeds in porous cloth bags were placed on blue silica gel, covered and placed in germination chamber set at 15 % relative humidity and 20 ^{0}C. Five lots of seeds were desiccated in silica gel until the target moisture contents of 6 %, 8 %, 10 %, 12 % and 18 % were attained. During desiccation, moisture contents were checked by frequent weighing and calculating moisture contents using the formula:

Seed weight at desired MC= initial weight of seed X (100-intial MC)/ (100-desired MC) (1)

Seed storage and germination testing

Twenty sub-samples of 2500 seeds for each MC were put in a bottle and tightly closed. All five MC regimes were replicated in four-temperature regimes storage at 6 ^{0}C, 15 ^{0}C, 25 ^{0}C and 35 ^{0}C in incubators maintained at respective storage temperature regimes. Seeds were removed at intervals of 30 days for a period of 150 days. Two samples for each MC treatment were taken to determine if seed MC changes occurred during storage. Samples were tested for germination by placing seeds on pre-prepared 1% (w/v) agar (plain agar) in distilled water in 9 cm Petri dishes and incubated in germination cabinets set at alternating temperatures 20/30 ^{0}C. Light was applied for 8 hours/day during the warm temperature phase (ISTA, 2007). Germination (viability) and vigour tests were performed by using four replicates of 25 seeds for each moisture contents for corresponding storage temperature. Germinated seeds were scored daily for up to 7 weeks. A seed was considered as normally germinated when the radicle protruded to 2–3 cm.

Measure of longevity

The time taken for germination to drop by 50% (p50) have been commonly used as a measure of longevity by many authors as it has the advantage of this period being the most accurately determined one (Probert, 2003; Muthoka, 2000; Roberts, 1983).

Results

Seeds Longevity Assessment by P_{50} for 150 days

In overall, seeds lost viability with increasing storage period. The time taken for viability to decline by 50 % is widely used as a measure of longevity in many wild plant species

(Probert, 2003; Muthoka, 2003). For both Baringo and Lodwar seedlots, the initial seed germination was approximately 86 % and 82 % and therefore P_{50} would be 43 % and 41 %, respectively. Essentially, P_{50} refers to the time, taken for viability to drop to 50 % percent of the initial germination (Newton *et al*., 2009). Seeds with 6 % and 8 % from both Lodwar and Baringo did not decline in viabilty to 50% (attain P_{50}) after storing for 150 days, while those with moisture content of 10, 12 and 18 % had declined in viability to 50% (P_{50}) between 29 and 6 days (Table 1). There seems to be variations between the two provenances on the time taken for at least 50 % of the seeds to have germinated under storage. In particular, seeds from the Lodwar provenance were shorter-lived with P_{50} of 29 and 30 days. On the other hand, seeds from the Baringo provenance were longer lived with P_{50} ranging between 29 and 75 days (Table 1).

Table 1. *Cordia sinensis* seeds longevity assessed by P_{50} for seeds stored at different temperature and different moisture contents (6, 8, 10, 12 and 18 % f.w.b).

Moisture content	**P_{50} viability at 6^0C**		**P_{50} viability at 15^0C**		**P_{50} viability at 25^0C**		**P_{50} viability at 35^0C**	
	Lodwar P_{50}(days)	Baringo P_{50}(days)	Lodwar P_{50}(days)	Baringo P_{50}(days)	Lodwar P_{50}(days)	Baringo P_{50}(days)	Lodwar P_{50}(days)	Baringo P_{50}(days)
6%	N/A	N/A	N/A	75	40	50	30	32
8%	N/A	N/A	30	70	25	45	20	31
10%	30	60	25	45	17	33	15	28
12%	20	40	17	35	9	30	7	26
18%	15	23	9	15	6	15	5	9

Seed viability, vigour and longevity

Cordia sinensis seed longevity, vigour and viability in storage gradually increased as the moisture contents decreased at constant storage temperature (Figures 1, 2, 3, 4). However, the longevity, vigour and viability also decreased as storage temperature increased (Figures 1, 2, 3, 4). The seed longevity, vigour and viability declined with increase of both moisture content and storage temperature, thus, the seed longevity and viability was in the order with respect to both MC and storage temperature as 6%>8%>10%>12%>18% and $6^{O}C>15^{0}C>25^{0}C>35\ ^{0}C$ respectively (Figures 1, 2, 3, 4). In overall, the two sites in terms of moisture content and storage temperature were not significantly different. There was statistically significant difference ($p<0.001$) in the moisture content (6 %, 8 %, 10 %, 12 % and 18 %) and also storage temperature (6 ^{0}C, 15 ^{0}C, 25 ^{0}C, 35 ^{0}C) for seeds sourced from the two sites.

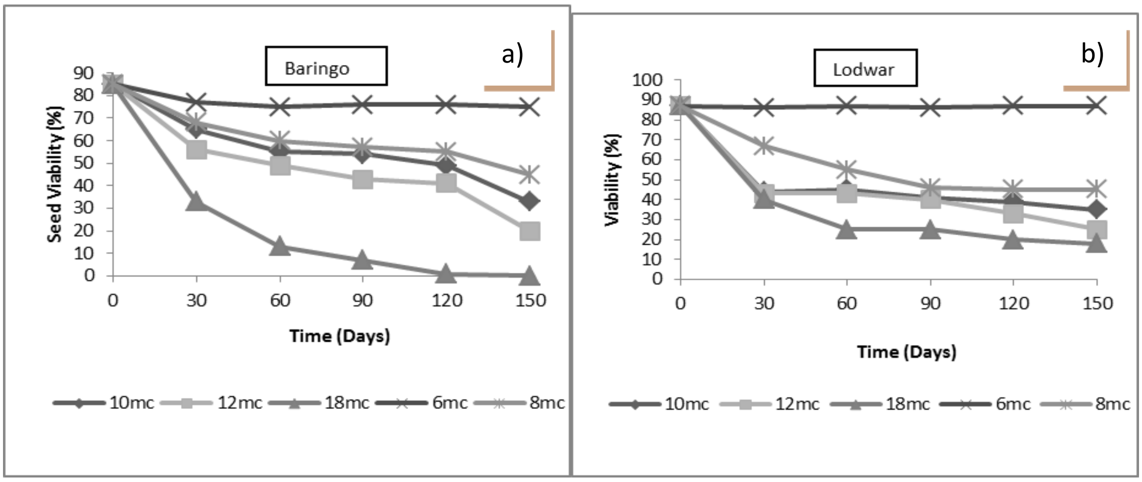

Figure 1a. Seed viability and longevity stored at 6 ^{0}C for 150 days

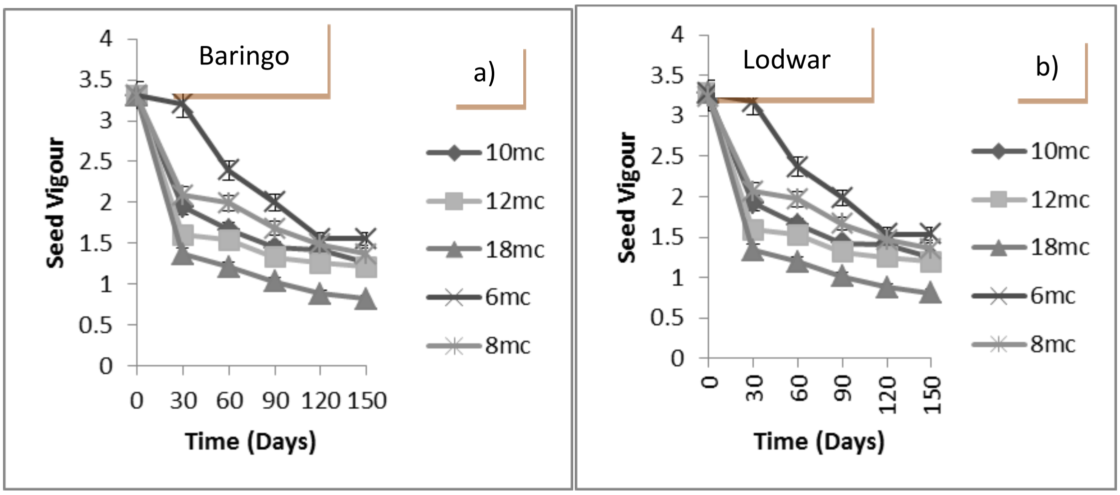

Figure 1b. Seed vigour and longevity stored at 6 ^{0}C for 150 days

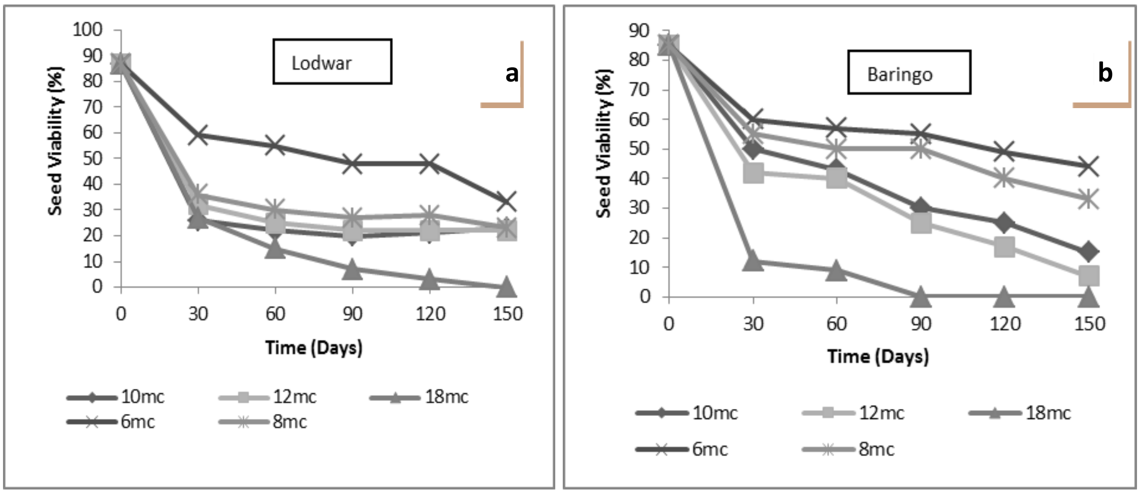

Figure 2a. Seed viability and longevity stored at 15 ^{0}C for 150 days

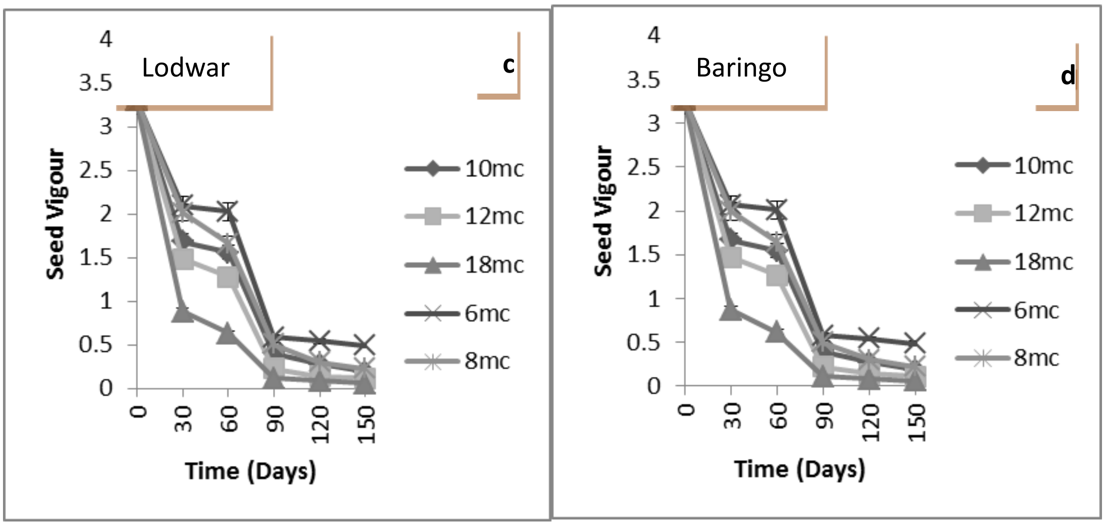

Figure 2b. Seed vigour and longevity stored at 15 ^{0}C for 150 days

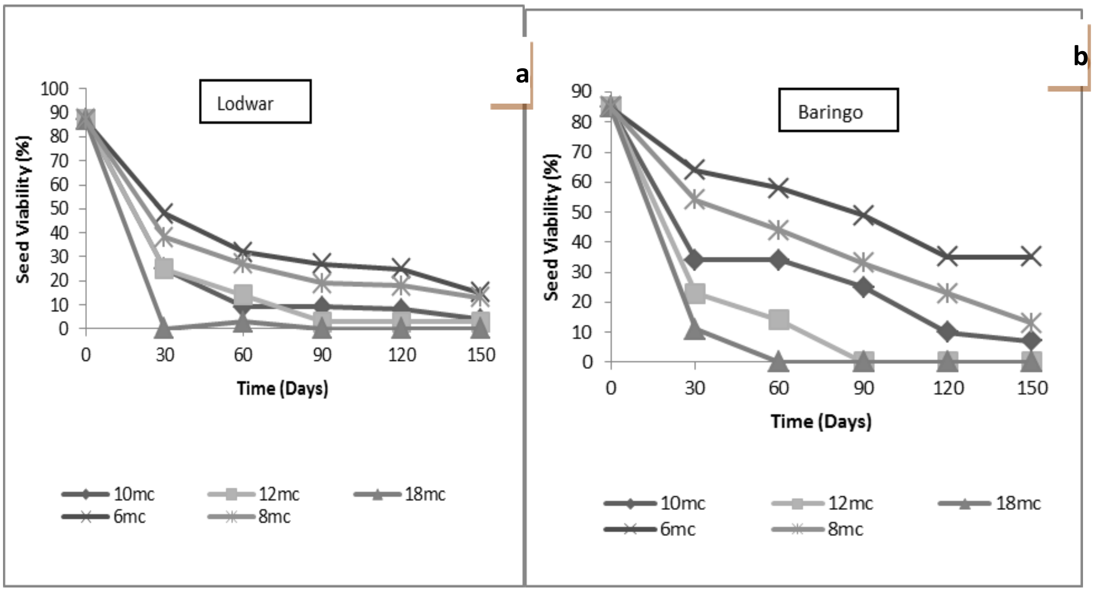

Figure 3a. Seed viability and longevity stored at 25 ^{0}C for 150 days

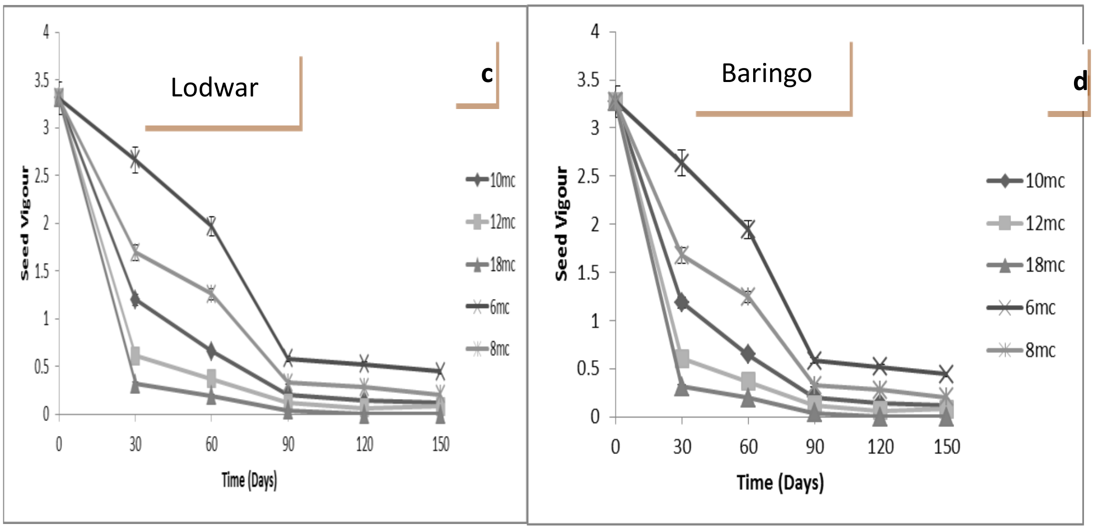

Figure 3b. Seed vigour and longevity stored at 25 ^{0}C for 150 days

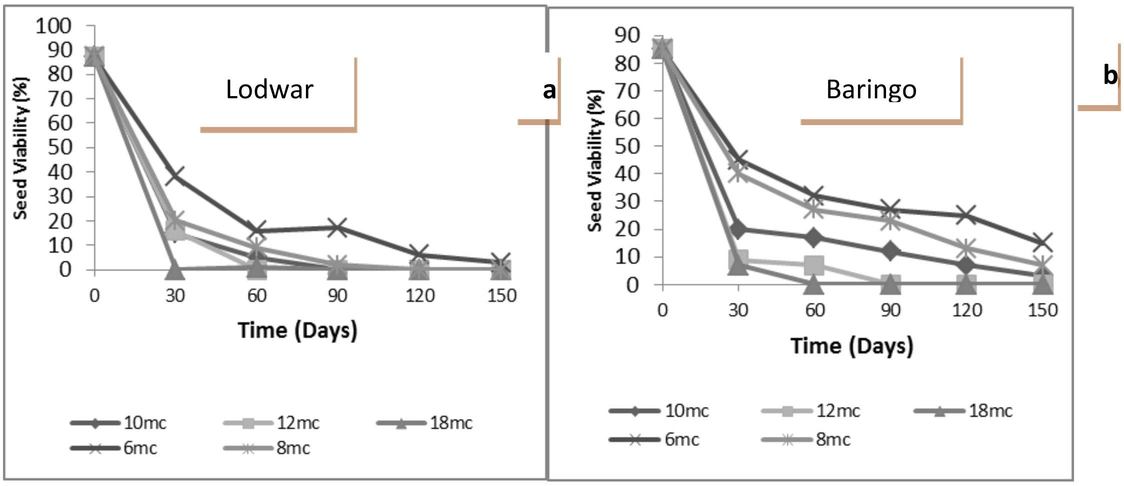

Figure 4a. Seed viability and longevity stored at 35 ^{0}C for 150 days

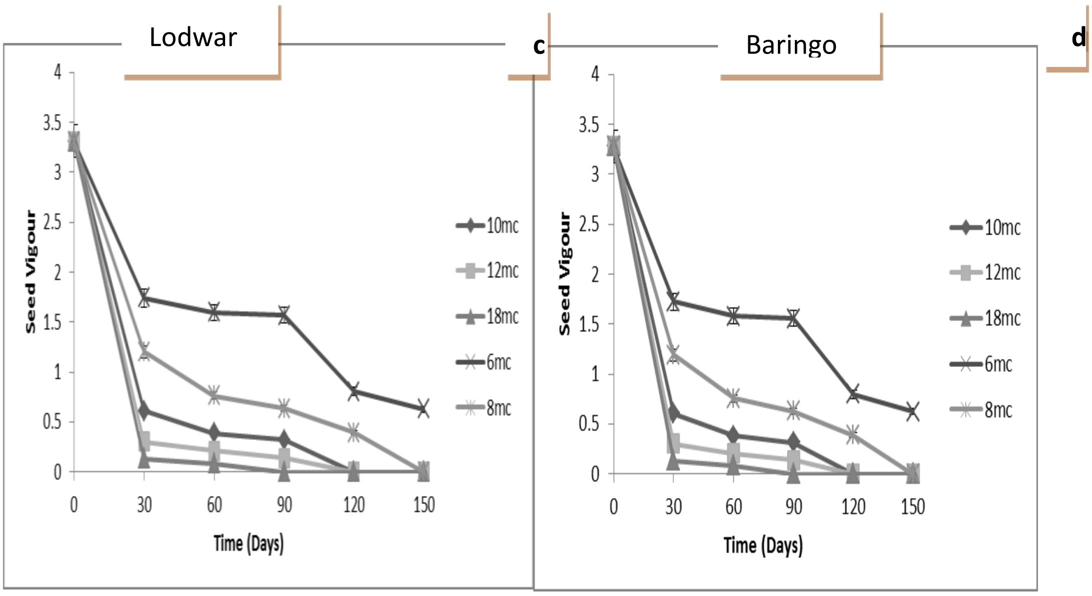

Figure 4b. Seed vigour and longevity stored at 35 ^{0}C for 150 days

Regression of time verses viability

In figure 5, the R^2 shows that, 56 % of the variation, dependent on viability is reduced by taking into account predictors of time, moisture content and temperature. The initial viability was approximately 86 % and not 100 % which R^2 would have given 100 %. It was difficult to explain this apparent anomaly unless one assumes that a certain percentage of the seed possibly were less mature (Austin, 1972) or of different genotype and were adversely affected by extraction method or storage temperature while the remainder was not. The graph exhibits a negative relationship where increase of both moisture contents and storage temperature caused decrease in viability over time.

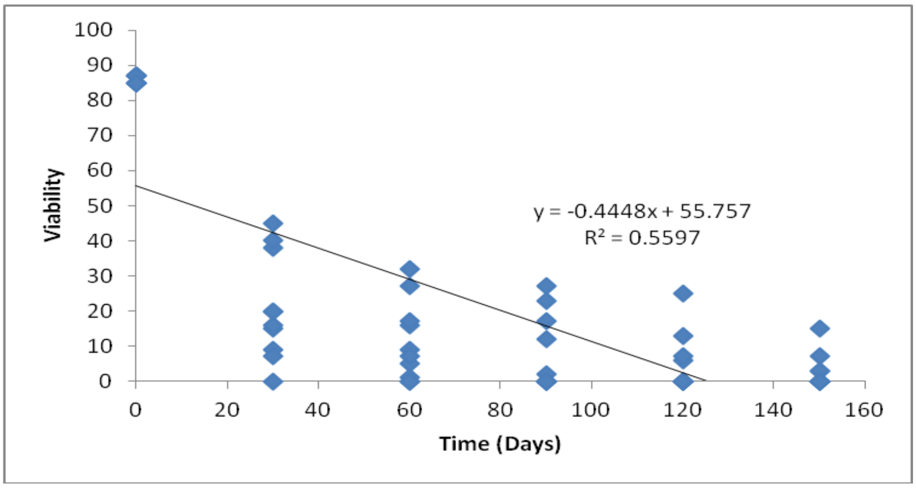

Figure 5. Regression of time verses seed viabilityDiscussion

There were short lived and long lived seeds in the results reported in this study. Seeds with low moisture content of 6 % had the longest life with both high viability and vigour compared to seeds with highest moisture content of 18% stored across all temperature regimes of 6 ^{0}C, 15 ^{0}C, 25 ^{0}C and 35 ^{0}C for 150 days. For example, the results for seeds with 18 %, 12 %, 10 %, 8 % and 6 % moisture content stored at 6 ^{0}C temperature revealed that with decrease of seed moisture content both seed viability and vigour period increased but there was a continuous decrease in both vigour and viability levels with time. Both Seed viability and vigour was in the order with mc as 6>8>10>12>18% for both study sites. This conforms to Orthodox seeds which conform to certain rules of the thumb that predict well the pattern of loss of viability in relation to storage environment (Roberts, 1983; Schmidt, 2000)

Again the results for same seeds with 18 %, 12 %, 10 %, 8 % and 6 % moisture content stored at 35 ^{0}C, 25 ^{0}C 15 ^{0}C and 6 ^{0}C revealed that with decrease of storage temperature, seed longevity period increased with time. Seed viability, vigour and longevity was in the order in respect to MC as 6>8>10>12>18% for both study sites. This again conforms to Orthodox seeds which conform to certain rules of the thumb that predict well the pattern of loss of viability in relation to storage environment (Bewley and Black, 1982)

Conclusion

The *Cordia sinensis* seeds can be classified as orthodox which is exhibited by seed with 6 % MC which gave highest longevity (shelf life) and higher viability in all storage temperatures.

Recommendation

The *Cordia sinensis* seeds can be stored for long period of time beyond 150 days they were subjected to storage. The optimal and best storage condition of *Cordia sinensis* are moisture content of 6 % and storage temperature of 6 ^{0}C for longer storage period, where cryopreservation is not available.

Acknowledgments

I wish to thank the Kenya Forestry Research Institute (KEFRI) for funding this study. I also thank the KEFRI field staff at Marigat and Lodwar for providing support during seed collection and both KEFRI tree seeds and biotechnology laboratories staff for providing support during seed testing.

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Applying Stage-based Matrix to Model the Invasive *Cestrum aurantiacum* Lindl. Population in Mount Elgon Ecosystem

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Abstract

Invasive plant species threaten global biodiversity, as well as ecosystem structure and functioning. In Kenya, *Cestrum aurantiacum* Lindl., is one of the main invasive species of concern to the country. Modeling of invasive species using stage based matrix methods has not been exploited to understand the population structure of invasive species. The study simulated stage-structured Lefkovitch models to assess the population structure and impact of *Cestrum aurantiacum* population growth within Mount Elgon Ecosystem. Data on distribution were collected on plots nested along the 1 km transects per forest block namely in Kaboywo, Kiptogot and Saboti. The plots were 300 m apart, and sub-plots were 1x1 m for seedling, 5 x 5 m for saplings and 10 x 20 m for mature plants. The average count of seedlings, sapling and adult *Cestrum aurantiacum* per sampled plots per forest block was recorded. The data were grouped for analysis and modeling, and for assessing the predisposing factors such as degradation, temperature, and deforestation. The survey data was used to calculate the transition probabilities and the growth rate which were as follows for the 3 blocks: Kiptogot $\lambda_1 = 1.074$ and Kimothon $\lambda_2 = 1.115$ and Saboti $\lambda_3 = 1.118$. These results indicate that that *Cestrum aurantiacum* population is invading forest ecosystem and adjacent farm lands, which are agriculturally productive. Thus with the increase of *Cestrum aurantiacum*, its population could have negative effects on the population of other native species within ecosystems in the future.

Keywords: Matrix models, Invasion species, degradation factors

Introduction

Invasive plant species threaten global biodiversity, as well as ecosystem structure and functioning (Levine *et al.*, 2003, Richardson *et al.*, 2000;Mack *et al.*, 2000). Consequently, these plants negatively affect the environment, human economy and human health (Mullah, 2014). The global cost of damage by invasive plant species is US$1.4 trillion per year, close to 5 % of global GDP (Cox, 2004). Species invasions are a principal component of global climatic change, causing large losses in biodiversity, as well as economic damage (Pimentel *et al.*, 2005). In the USA alone, it is estimated that invasive species cause damage of up to USD137.2 billion per year (Pimentel *et al.*, 2005) for agricultural losses, with worldwide losses reaching USD 248 billion (Cox, 2004). The negative effect of invasion has resulted into increased level of poverty and slowed down economic growth and development particularly among the developing countries, since they rely mostly on agricultural activities for their livelihoods and growth (Levine *et al.,* 2003).

Worldwide alien plants invasions of protected forest areas are increasing and are widely recognized by forest and environmental managers as a major threat (Padmanaba *et al.,* 2017; Foxcroft *et al.,* 2017). According to Arim *et al.* (2006), invasive species threaten almost 60 % of the species listed in the U.S. Endangered Species Act. Thus, better understanding of the population structure of these invasive plants and mechanisms of invasion is crucial to ecological research and conservation planning.

One of the common invasive plant species is *Cestrum aurantiacum* Lindl., a shrub, which grows upto 1 to 3 m high, and produces flowers for several months through summer and autumn. The plant is long-lived, producing new growth in spring. The seeds of *Cestrum aurantiacum* remain dormant in the soil for many years. The shrub prefers moist habitats that are commonly found along roadsides, neglected, disturbed and abandoned sites (Global Invasive Species Database, 2018). The plant is one of the major invasive species in Kenya. However, little is known about its developmental stages, to aid its management.

Mathematical modelling provides insight into problems by establishing mathematical relationships among the variables and parameters (Caswell, 2010) that affects populations of various flora and fauna. The theory of describing, predicting and analyzing population growth by analyzing life history parameters such as survival and fecundity can be traced back to in 1895 Cannan (Caswell, 2010). The matrix models were first developed by Bernardelli (1941), Lewis (1942), and Leslie (1945). Matrix model that classified the population based on the stage of life was modified by Lefkovitch and is a modification of Leslie matrix where the classifications were replaced by life stage (Caswell, 2001). Caswell (2010) treated the density as a sum of all individuals in the population, setting up a matrix model with a population partitioned into stage classes.

This study used stage based matrix models techniques of grouping the population of *Cestrum aurantiacum* into development stages in order to understand their structure and system within Mt Elgon, Kenya.

Materials and Methods

Study area

The study was carried out in Mt. Elgon ecosystem, which lies between 0°52' and 01°25N, and between 34°14' and 34°44'E. The area, which is a trans-boundary natural ecosystem resource between Kenya and Uganda, covers 2,223 square kilometers with 1,078 square kilometers falling on the Kenyan side. The ecosystem covers an area of about 772,300 hectares consisting of 221,401 hectares of protected areas and 550,899 hectares of farmlands and settlements of which 180,000 hectares of the forest are in Kenya.

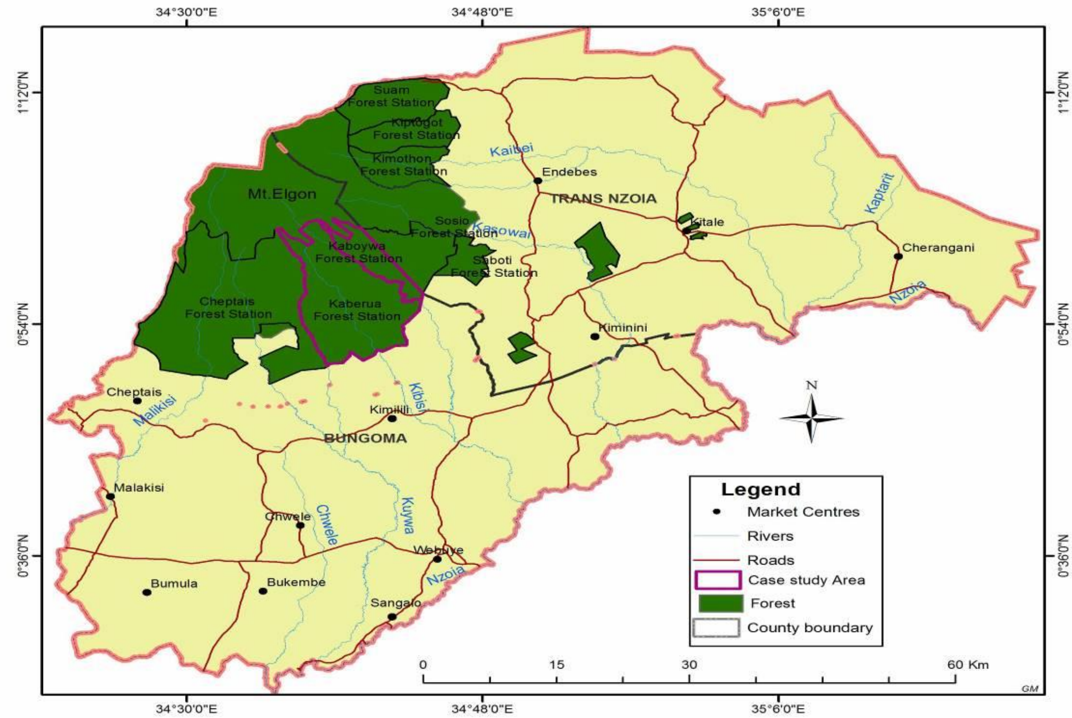


Figure 1. Map of Mt Elgon forest Blocks

Sampling methods

To build a mathematical model that simulates the population size and structure of invasive species of *Cestrum aurantiacum*, classified forest block within the ecosystem was used. Data on distribution were collected on the plots nested along the 1 km transects per forest block namely in Kaboywo, Kiptogot and Saboti. The plots were 300 m apart. The sub-plots were 1x1 m for seedling, 5 x 5 m for saplings and 10 x 20 m for mature plants. The average count of seedlings, sapling and adult *Cestrum aurantiacum* per sampled plots per forest block was recorded and grouped for analysis and modeling, and for assessing the predisposing factors such as degradation, temperature, and deforestation.

Model estimation and construction

In this study, all the parameters were estimated based on the data collected during the preliminary research. The population projection matrix (A)), contains the survival probabilities and reproductive rates estimated within each forest block considering that all the predisposing factors are homogeneous per forest block. The computations of the entries of matrix (A) are given (Table 1).

Table 1. Model Parameters computation methods

Parameter	Notation	Meaning	Computation method
Fertility rate	Fi (*Fi* >0)	The rates which is the number of offspring of stage age i to (i + 1) in a unit of time t that will survive to the next stage class at time (t+1) (Bruce and Shernock, 2002)	Reproductive Contribution. $F_i = b(i)P_i$ Where b(i) = specific fecundity rate and Si = the probability of surviving to the adult stage. The value was estimated using the total number of added seedling sampled within the period of survey (Gotelli, 2001).
*S*urvival rate	(0 < *Si* >1)	Is the probability that an individual of stage i at time t will survive to time (t+1), and remain in the same stage	($Si= \delta_i \ (1-\gamma_i)$) Where δ_i is the survival probability of stage i and γ_i the probability that a surviving individual grows from stage i to stage (i+1). Estimated from the data
Transition rate	Gi	The probability of surviving and growing from stage i to stage ***(i+1)*** given by *(*Musick and Bonfil, 2005)	($Gi= \delta_i \ \gamma_i$) The value was estimated from the data assuming the rate of death per stage is a ninth of the survival rate
Eigen value	(λ)	Long term population growth rate	$\det(A-\lambda I)=0$
Eigen vectors	v	Long term population structure corresponding to specific eigenvalues	Once the eigenvalues of a matrix (A) have been found, the Eigenvectors by Gaussian Elimination can be found

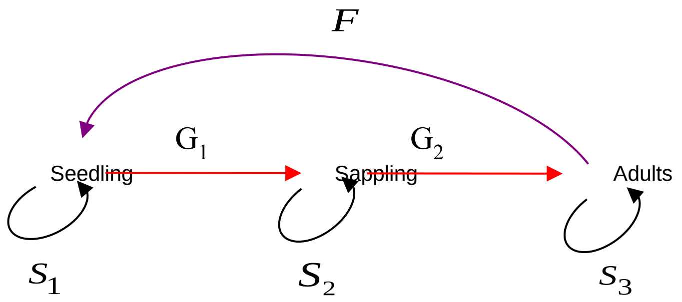
The model stage based matrix (A) model is given below:

$$A=\begin{bmatrix} S_{11} & 0 & F \\ G_{12} & S_{22} & 0 \\ 0 & G_{23} & S_{33} \end{bmatrix} \qquad (1)$$

Under this model, the population projection matrix (A) is used to get the projected population at time (t+1) denoted by the equation 3 given below:

$$n\ (t+1) = A\ n\ (t), \qquad (2)$$

Where $\boldsymbol{n}$ represents a vector of stage class population structure at times (t + 1) and t, respectively. The elements of the square matrix $\boldsymbol{A}$ are non-negative, the elements of the first row are greater than or equal to zero, the elements of its main sub-diagonal are positive and less than unity and the remaining elements are zero. The stage based model is shown by a life-cycle interaction and/or transition among the stages.



Results and Discussion

Projection Matrices

Projection matrix (A) parameters used in the analysis of the growth rate considering that the predisposing factors observed: temperature, rainfall and degradation; are homogenous per forest blocks. The estimates model parameters presented in the Table 2 below are point estimates.

Table 2. Model parameters of *Cestrum aurantiacum*

Forest block	**Survival per stage**	**(Sii)**	**(Gij)**	**Mean Population**	**Eigen value λ**	**Eigen vector**
Kimothon						
Stage 1	0.762559	0.084729	0.782103	319		
Stage 2	0.869203	0.096578	0.718943	248	2.94	(0.96,0.26, 0.11)
Stage 3	0.814133	0.090459	0.678481	148		
	0.815298	0.090589	0.726428	714		
Saboti						
Stage 1	0.882948	0.098105	0.722581	315		
Stage 2	0.815773	0.090641	0.729302	313	3.14	(0.96,0.28, 0.10)
Stage 3	0.870143	0.096683	0.672	142		
	0.856288	0.095143	0.70796	770		
Kiptogot						
Stage 1	0.788822	0.087647	0.695495	666		
Stage 2	0.855783	0.095087	0.715789	329	3.49	(0.97,0.23, 0.07)
Stage 3	0.774339	0.086038	0.768	225		
	0.806315	0.089591	0.726508	1220		

The following are the stage based population modeling matrix for the different forest block:

$$A_{Kiptogot} = \begin{bmatrix} 0.088 & 0 & 46 \\ 0.789 & 0.095 & 0 \\ 0 & 0.856 & 0.806 \end{bmatrix}, \; A_{Kimothon} = \begin{bmatrix} 0.0966 & 0 & 26 \\ 0.763 & 0.085 & 0 \\ 0 & 0.869 & 0.814 \end{bmatrix},$$

$$A_{Saboti} = \begin{bmatrix} 0.099 & 0 & 29 \\ 0.883 & 0.098 & 0 \\ 0 & 0.816 & 0.870 \end{bmatrix}, \qquad (3)$$

The Eigen value of the population projection matrix, is denoted by lambda, which is the growth rate of the population. If lambda = 1, there is no change in the population size but if lambda is > 1, then the population is increasing, while values of lambda < 1 indicate that the population is decreasing.

Growth rates of the population of invasive species per block

Figures 2 and 3 show the projection of the population per forest block and the extrapolated population within 100 months. The results indicate a higher population count in Kiptogot block than other forest blocks, mainly because the Kiptogot block was more disturbed than the other two blocks. The disturbance in the block is as a result of destruction and degradation (Ongugo *et al.*, 2017). The forests in these areas have been modified considerably over the years by human activities especially through urbanization, deforestation and intensive agricultural practices. Increased human population and demand for more agricultural land for food production exacerbate the disturbance, which has resulted in destruction of the vegetation cover, and subsequently rampant environmental degradation and deforestation (Ongugo *et al.*, 2017)

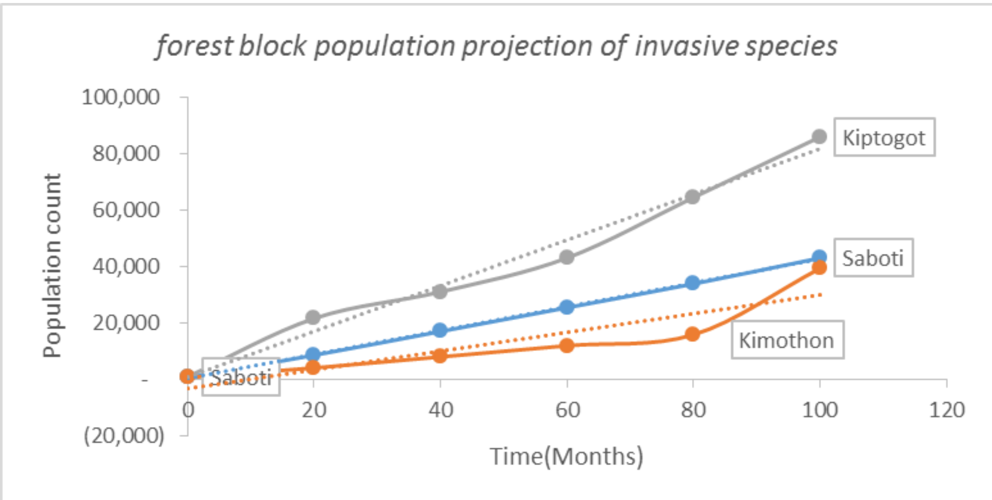


Figure 1. Forest block population projection of *Cestrum aurantiacum* over a period of 100 months

There was an increase in the population of the seedlings, saplings and adult plants of the species, hence the need for population management within all the forest blocks (Figure 3). The results are consistent with the findings of Ogungo *et al*. (2017), that various degraded sites in Mt. Elgon ecosystems were within the forest reserves which consist of: closed natural forest, forest plantation, open natural forest and shrub land; and private farms, hence the main drivers of invasion by these species. Ogungo *et al*. (2017) reported that the main pre-disposing factors that are drivers of degradation within the forest are over-grazing of livestock, as well as illegal harvesting of timber, charcoal production, agriculture and settlement.

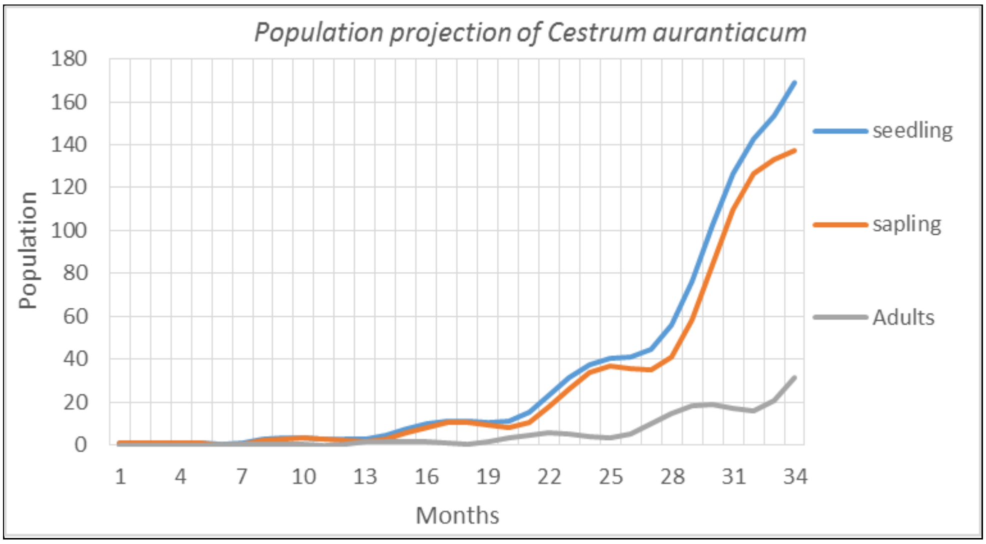


Figure 3. Population projection of *Cestrum aurantiacum* per stage in Mt Elgon

Potential Impacts of *Cestrum aurantiacum* on Mt Elgon and adjacent landscape

There are at least two major adverse effects of the existence of an invasive species in a native ecosystem. First, invasive plants change native ecosystem processes such as nutrient or hydrology cycles and contribute to the decrease of native species abundance (Mack *et al.*, 2000; Mullah, 2014). Secondly, invasive species such as *Cestrum aurantiacum* are toxic to animals like sheep and goats (Mullah, 2012), and may have a similar effect on humans (McLennan *et al.*, 1984). The main concern on the effect of increase of *Cestrum aurantiacum* population as invasive species is by invading remnant forest ecosystem within Mt Elgon water towers. This could potentially invade the forest adjacent farmlands, which are agriculturally productive and are the food basket of the western region of Kenya. Lastly, these native forests maintain ecosystem services that include the hydrological balance and provide habitat and food for native animals hence a major threat by *Cestrum aurantiacum*.

Conclusion

The results from this preliminary study shows that population of *Cestrum aurantiacum* is on the increase as indicted by the stage based population structure and may have a negative impact on the indigenous plant species, and other effects. However, to further estimate the population and magnitude of the impact, there is need to incorporate more environmental factors, which may play a role in the invasion per forest block. Further studies can be done to assess the effects of different levels of degradation factors and the variation of the effects on the population growth per stage of growth.

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Effects of Integrated Use of Plant Residues and Urea on Maize Yield Components Under Striga Infestation in Western Kenya

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Abstract

Declining soil fertility and *Striga hermonthica* (Delile) Benth. infestation are serious threats to sustainable food production in western Kenya. Appropriate soil fertility regimes are therefore critical for Striga management and improved maize productivity. The effect of integrated use of urea and Calliandra or maize stover on Striga infestation and maize yield components was assessed. A field experiment was carried out for five consecutive seasons on a clay loam Ferralsol in western Kenya. Urea and Calliandra or maize stover were combined to supply nitrogen (N) at 75 kg ha^{-1} from both sources in 0:0, 100:0, 80:20, 60:40, 40:60, 20:80, 0:100 ratios. A randomized complete block design (RCBD) with 12 treatments replicated four times was used with maize hybrid (WS 502) as a test crop. Data was collected on maize traits and yield and subjected to Analysis of Variance. All the three ear traits: ears per plant, ear length, and ear diameter; kernels per row; and grain yields were significantly higher where Calliandra was applied at (45 kg N ha^{-1}) combined with urea (30 kg N ha^{-1}) and Calliandra (30 kgN ha^{-1}) combined with urea (45 kg N ha^{-1}) or maize stover (45 kgN/ha^{-1}) combined with urea (30 kg N /ha^{-1}) and maize stover (30 kg N/ha^{-1}) combined with urea (45 kg N /ha^{-1}). Number of ears per plant was a major yield component R^2=0.74. Stepwise regression analysis showed ears per plant to be the most important yield component under *Striga* infestation (R^2=0.58), followed by kernels per row (R^2=0.38). The control and sole maize stover treatments had the most severe reduction in all yield components. Calliandra (45 kg N ha^{-1}) combined with urea (30 kg N ha^{-1})) and maize stover (15 kg N ha^{-1}) combined with urea (60 kg N ha^{-1}) had consistently lower Striga infestation compared to all other treatments. These treatments reduced Striga probably due to the combined effects of suicidal germination of the Striga seed and increasing inorganic (N) in the soil, which has a negative effect on Striga. Reduction in maize grain yield and its components were more severe under moisture stress that occurred in short rain seasons.

Introduction

Soil fertility decline is increasingly viewed as a critical challenge affecting agricultural productivity and environmental welfare in Sub-Saharan Africa (SSA) (Bationo *et al*., 2004). Studies indicate that the decline is as a result of a combination of high rate of erosion, leaching, removal of crop residues, and continuous cultivation of land without adequate fertilization or fallowing (Sanchez and Jama, 2002). This is aggravated by the inherent poor fertility in most tropical soils (Okalebo *et al*., 2003). Consequently, SSA has experienced a decrease in overall per capita food production with soil fertility being recognized as the fundamental root cause for declining food security.

In Kenya, maize (*Zea mays L.)* is a major food crop and dominates all food security considerations with a per capita consumption of 103 $kgyr^{-1}$. Smallholder famers in western Kenya rely on maize as the staple food crop, but its production is low, estimated at 0.5 to 1.5 t/ha^{-1} yr^{-1} (Ouma *et al*., 2002) against a production potential of 4 t/ha^{-1} yr^{-1}. The major cause of this low yield is soil nutrient depletion, indicated by negative nutrient balances. The average annual loss in soil nutrients of 42 kg N, 3 kg P and 29 kg K ha^{-1} in Kenya is among the greatest in Africa. Reversal of soil fertility depletion is therefore required to increase per capita agricultural production.

The problem of soil infertility in western Kenya is exacerbated by climate change and variability that increasingly affects farming operations. In addition, the buildup of *Striga hermonthica* (Del) Benth (witchweed) that attacks cereals, which are important staples in the region (Vanlauwe *et al*., 2008), is associated with declining soil fertility resulting from continuous-intensive cropping without adequate fertilizer inputs (Tittonell, *et al*., 2005; Vanlauwe *et al*., 2008), a common phenomenon in densely populated farming systems of western Kenya (Vanlauwe *et al*, 2006). Striga weed is known to cause crop yield losses of between 20 and 100 % for maize (Kim *et al*., 2002; Midega *et al.*, 2017; Vanlauwe *et al*., 2008) and 20 to 50 % in sorghum (Lendzemo *et al*., 2005; Midega *et al.*, 2017), although 100 % yield loss is not uncommon. Striga infests about 217,000 hectatres (about 15 % of the arable land) in the Lake Victoria basin of Kenya (www.fao.org; CEPA, 2004), causing annual crop losses estimated at $53 million (Woomer and Savala, 2009).

Use of mineral fertilizers is one of the major ways to replenish soil nutrients. Positive agronomic responses to fertilizers have been demonstrated for many crops (Bekunda *et al*., 1997), but fertilizer use in western Kenya region remains low largely due to socio-economic factors (Sanchez, 2002; Okalebo, 2000). An alternative to mineral fertilizer is the utilization of organic fertilizers such as crop residues, composts, farm yard manure and green manure, as well as the application of conservation principles and practices. Biomass transfer from trees and shrubs have also been used as sources of plant nutrients (Jama *et al*., 2000). However, the use of organic fertilizers is limited by inadequate quantities, low and variable nutrient content, high labour requirement and competitive uses (Jama *et al.*, 2000). Despite the above limitations, soil productivity must be restored in western Kenya in order to ensure food security and poverty reduction.

Integrated Soil Fertility Management (ISFM) has been demonstrated as a strategy that can address the complexities and peculiarities of soil fertility management on smallholder farms. This helps low resource endowed farmers to mitigate problems of poverty and food insecurity by improving the quantity of food, income and resilience of soil productive capacity (Bationo *et al.*, 2003). Integrated Soil Fertility Management involving the combined use of organic and mineral resources, resilient germplasm and nutrient cycling and conservation (Vanlauwe *et al*, 2010), is an overarching approach to restoring and maintaining soil productivity. This is reported to result into synergy and improved conservation and synchronization of nutrient release and crop demand, leading to increased fertilizer use efficiency and higher yields (Vanlauwe *et al.*, 2002).

Yield, which is a quantitative trait, is functionally related to yield components. Information on the effect of ISMS on maize yield components under Striga infestation could be useful to physiologists, modelers and agronomists. However, such information is scanty in literature. The information could provide a vehicle for increasing efficiency of input and resource use by the crop, reducing the risks farmers face in using purchased inputs and perhaps encourage the adoption of improved technologies. The objective of this study was therefore to assess the effect of applying organic residues solely or in combination with urea on Striga infestation and maize yield components under small-scale farming conditions in western Kenya.

Materials and methods

Experimental site

This study was conducted at Nyabeda (N 0° 08', E 34° 24') in Siaya County, western Kenya. The area is classified as midlands (LM 2) with an altitude of approximately 1330 m above sea level. Rainfall is bimodal, with two cropping seasons a year. Long rains start from March and end in July and the short rain start from August and end in November, with a mean annual rainfall of 1800 mm (Figure 1). Mean annual temperature ranges between 22 ^{0}C and 24 ^{0}C. The soils are classified as Ferralsols/Nitisols (Kandiudalfic Eutrudox), clayey, reddish, deep and well drained. The soil chemical and physical properties at the onset of the experiment are shown in Table 1.

Table 1. Properties of 0-15 cm deep soil at Nyabeda experiment site in western Kenya

Attribute	Value
pH (1: 2.5 soil:water)	6.1
Organic C (%)	2.33
Total N (%)	0.23
Olsen P (mg Kg^{-1})	2.75
Calcium ($cmol_c$ Kg^{-1})	7.96
Magnesium ($cmol_c$ Kg^{-1})	4.78
Potassium ($cmol_c$ Kg^{-1})	0.05
Sodium ($cmol_c$ Kg^{-1})	0.40
Exchangeable bases ($cmol_c$ Kg^{-1})	13.2
Clay (%)	23

Silt (%)	14
Sand (%)	63

Experimental design, establishment and management

The experiment was set in a randomized complete block design (RCBD) with twelve treatments replicated four times. Treatments consisted of two organic sources of N (maize stover and residues of *Calliandra calothyrus* Messn.) and urea as the inorganic mineral source of N. Treatments were combined in the following ratios: 0:0, 100:0, 80:20, 60:40, 40:60, 20:80, and 0:100 so as to supply a total of 75 kg N ha^{-1} per treatment except the control which had a ratio of 0:0 with no N inputs (Table 2). Maize stover was obtained from neighbouring farms and Calliandra from an established demonstration plot within the area. In each season before their use, a sub sample of each organic input was anayzed for N content to determine the quantity to be applied. The plant residues were then weighed, chopped and incorported into the soil at a depth of 15 cm during land preparation in all seasons. Phosphorus (P) and potassium (K) were uniformly applied to each plot of 6 x 6 m at the rate of 40 kg P and 20 kg K ha^{-1} as triple super phosphate and muriate of potash respectively at the beginning of each season. One day after treatment application, maize variety WH502 was planted at a spacing of 75 cm between rows and 25 cm within rows. Two seeds were planted per hill and thinned to one seedling per hill two weeks after emergence (WAE), to give a total maize population of 53,333 plants ha^{-1}. Weeding was done at three and eight weeks after planting. In the appropriate treatments, urea was applied in splits with one third being applied at planting, while the rest was applied as a topdress six weeks later.

Table 2. Details of treatments used in the field trial

Treatment No	Organics	N from Organics	N provided by urea (kg ha^{-1})	Total N
1	None	0	0	O
2	Calliandra	75	0	75
3	Calliandra	60	15	75
4	Calliandra	45	30	75
5	Calliandra	30	45	75
6	Calliandra	15	60	75
7	Maize stover	75	0	75
8	Maize stover	60	15	75
9	Maize stover	45	30	75
10	Maize stover	30	45	75
11	Maize stover	15	60	75
12	None	0	75	75

Striga count and collection in the field

Data were collected on Striga infestation in all the plots. Striga shoots that emerged in the field were counted in the six middle rows (4.5 x 6 m) at 2 week intervals starting from the day of Striga appearance, and the maximum number of shoots recorded in each plot was documented as Striga infestation. Striga emergence data were converted to the number of Striga plants m^{-2}. All Striga plants collected were sun dried and their weights recorded. Data was collected only on plants in the two central rows. Data on maize damage score was based on a scale of 1 to 9 at 10 weeks after planting of maize. Details of the rating are as follows:

1= normal plant growth, no visible symptoms,
2= small and vague purplish-brown leaf blotchets visible
3=mild leaf blotching with some purplish-brown necrotic spots
4=Extensive blotching and mild wilting. Slight but noticeable stunting and reduction in ear and tassle size
5= Extensive leaf blotching, wilting and some scorching, moderate stunting, ear and tassle size reduction
6= Extensive leaf blotching with mostly fray necrotic spots. Some stunting and reduction in stem diameter, ear size and tassel size.
7= Definite leaf scorching, with gray necrotic spots, and leaf wilting and rolling. Severe stunting and reduction in stem diameter, ear size, and tassel size, often causing stalk lodging, brittleness, and husk opening at a late-growing stage.
8=Definite leaf scorching with extensive gray necrotic spots. Conspicuous stunting, leaf wilting, rolling, severe stalk lodging, and brittleness, reduction in stem diameter, ear size and tassel size.
9= complete scorching of all leaves, causing premature death or collapse of host plant and no ear formation

Results and Discussions

Effect of organic and inorganic N sources on soil inorganic N dynamics

Soil mineral N showed significant differences ($p<0.01$) at 4 and 12 Weeks After Planting (WAP). There was a general increase in N from 4 to 8 WAP followed by a decrease to 12 WAP (Table 3). Maize stover applied at 30 kg N ha^{-1} combined with urea at 45 kg N ha^{-1} gave the highest mineral N of 56 and 59 kg N ha^{-1} at 4 and 8 WAP respectively. The same treatment increased soil mineral N above the control by 24 and 20 kg N ha^{-1} on average, representing 74 to 50 % increases at 4 and 8 WAP respectively. At 12 WAP Calliandra applied at 15 kg N ha^{-1} combined with urea at 60 kg N ha^{-1} gave the highest mineral N of 51.4 kg N ha^{-1}. The same treatment increased soil mineral N by 18 % compared to the control. Treatments with over 45 kg N $ha^{-1}$of maize stover had lower levels of mineral N at 4 and 12 WAP.

Table 3. Total soil inorganic nitrogen at 0-15 cm soil depth sampled at different periods during 2007 long rains and short rains at Nyabeda

Treatments		**Long rainy season**			**Short rainy season**		
		4 WAP	**8WAP**	**12 WAP**	**4 WAP**	**8WAP**	**12 WAP**
Organic	**Urea**			**Mineral N (Kg ha^{-1})**			
Control		32.4	39.3	43.70	30.7	26.3	13.2
75CC	0U	45.1	46.9	32.42	27.5	30.6	25.9
60CC	15U	48.5	51.3	35.37	19.3	31.1	16.5
45CC	30U	47.3	36.9	36.00	24.8	35.8	13.1
30CC	45U	42.9	48.0	42.30	36.5	27.1	22.1
15CC	60U	42.6	40.8	51.36	35.1	24.6	18.5
75MS	0U	29.4	48.1	33.23	32.0	26.5	12.5
60MS	15U	28.7	45.0	31.42	31.0	28.7	14.3
45MS	30U	27.9	41.1	32.08	29.0	26.2	26.7
30MS	45U	56.0	59.0	36.63	26.7	39.8	22.8
15MS	60U	40.9	46.4	39.20	28.3	30.6	17.4
0	75U	48.4	47.9	39.98	24.4	24.0	17.5
Mean		40.9	45.9	37.81	29.6	29.3	18.4
P level		<0.001	0.30	<0.001	0.490	<0.001	<0.001
lsd		10.29	15.38	3.01	14.00	3.30	2.20
CV		7.3	15.4	2.6	8.70	5.70	8.60

CC=Calliandra, MS =maize stover, U=urea, WAP=weeks after planting

During the 2007 short rains, significant treatment effects (p<0.001) were observed at 8 and 12 WAP respectively (Table 3). There was a general reduction in soil mineral N levels from 4 to 12 WAP. Maize stover applied at 30 kg N ha^{-1} combined with urea at 45 kg N ha^{-1} gave the highest mineral N of 39.8 and 56 kg N ha^{-1} at 8 and 12 WAP respectively. The same treatment increased soil mineral N by 34 % and 51 % compared to the control at 8 and 12 WAP respectively. This was followed by Calliandra applied at 45 kg N ha^{-1} combined with urea at 30 kg N ha^{-1} that recorded 35.8 kg N ha^{-1}. At 8 WAP, Calliandra applied at 75, 60, 45 kg N ha^{-1}, and maize stover at 30 and 15 kg N ha^{-1} had significantly higher soil mineral N than the control. With the exception of maize stover at 60 and 75kg N ha^{-1} all other treatments had higher soil mineral N than the control at 12 WAP. Maize stover applied at 75 and 60 kg N ha^{-1} depressed soil mineral N compared to the control at 12 WAP. Soil mineral N levels were generally higher in the long rain season compared to the short rain season.

The different patterns observed in the amounts of soil inorganic N at the different sampling times was attributed to differences in rainfall patterns, decomposition rates and N release patterns of the two plant residues (*Calliandra* and maize stover) used in the study and the proportion in which two were combined with urea. The increase in mineral N from 4 to 8 WAP could be attributed to N release through mineralization and N added as urea at 6 WAP as topdressing.

Reduction of soil inorganic N from 8 WAP to 12 WAP was mainly attributed to decrease in mineralization, N uptake by plants coupled with N denitrification, immobilization and leaching. Leaching can result in appreciable loss of topsoil NO^-_3. The loss through leaching was more likely due to high amounts of rainfall received during this period (Figure 1). Such phenomenon was reported by Thornton *et al*. (1995) who estimated 40 to 50 % of the mineralized N being lost under high rainfall environments through leaching and Myers *et al*. (1997) who noted that leaching of mineral N in the soil increased as the rainfall amount increased. However, reduction in soil inorganic N noted in 2007 short rain season is most likely attributed to low and unreliable rainfall that was received in that season (Figure 1). Soil moisture plays an important role in decomposition, N release and movement in the soil. The difference between the amounts of inorganic N between the two seasons may be related to the previous season's rainfall and crop yield.

The consistently higher amount of mineral N under maize stover applied at 30 kg N ha^{-1} combined with urea at 45 kg N ha^{-} at 4 to 8 WAP could be attributed to the higher proportion of urea applied at planting. This early and consistent supply of N is important for crop development (Serrem, 2006). This may therefore explain the higher yields realized under these treatments. Low levels of mineral N in plots with high levels maize stover could be attributed to slower rates of decomposition and N release. Low quality organic materials such as maize stover with high C/N ratio take long to decompose and release N for plant uptake. Addition of organic materials with a total N content of 1.5% can trigger N immobilization in soil. The maize stover that was applied in this study had a total N content of 0.65 %, which was below the critical level suggested by Palm *et al*. (2001). The benefits of such residues to the crop may be through the long-term buildup of N rather than the direct use of N from the decomposing residues.

Maize damage score and mergence Striga count

Seasonal trends in Striga incidence over the period of study are summarized in Table 4. There were highly significant ($p<0.001$) differences between seasons. Except for 2007 shirt rains, ($p<0.001$) effects of treatments on Striga counts were not significant in all other seasons. The highest Striga densities of 115 plants m^{-2} were observed in sole maize stover applied at 75 kg N ha^{-1} and maize stover applied at 60 kg N ha^{-1} combined with urea at 15 kg N $ha^{-1}$with 114 plants m^{-2}). The two treatments had significantly higher Striga counts than all other treatments. Averaged over five seasons, Striga density was higher in the control and in treatments receiving more than 80 % of N from maize stover (Table 4). In 2007 and 2008, Striga emergence was higher during long rains than the short rain seasons. The season by treatment interaction on Striga intensity was not significant ($p=0.65$).

Table 4. Effect of combined use organic residues and urea on Striga counts at Nyabeda, western Kenya (values in brackets are transformed values of Striga incidence $\log_{10}$ (x+1)

Treatments	Seasons				
	LR2007	**SR2007**	**LR2008**	**SR2008**	**LR2009**
	Plants m^{-2}				
Control	118 (2.07)	57 (1.76)	19 (1.28)	4 (0.60)	11 (1.04)
75CC+0U	146 (2.16)	45 (1.65)	13 (1.11)	4 (0.60)	9 (0.95)
60CC+15U	128 (2.11)	65 (1.81)	16 (1.20)	7 (0.85)	14 (1.15)
45CC+30U	117 (2.07)	29 (1.46)	10 (1.0)	4 (0.60)	12 (1.08)
30CC+45U	100 (2.0)	55 (1.74)	12 (1.08)	3 (0.48)	11 (1.04)
15CC+60U	105 (2.02)	38 (1.58)	13 (1.11)	4 (0.60)	8 (0.90)
75MS+0U	89 (1.95)	115 (2.06)	15 (1.18)	3 (0.48)	15 (1.18)
60MS+15U	141 (2.15)	114 (2.06)	16 (1.20)	7 (0.85)	15 (1.18)
45MS+30U	44 (1.64)	49 (1.69)	6 (0.78)	3 (0.48)	9 (0.95)
30MS+45U	68 (1.83)	37 (1.57)	9 (0.95)	5 (0.70)	8 (0.90)
15MS+60U	154 (2.19)	40 (1.60)	8 (0.90)	4 (0.60)	14 (1.15)
75U	126 (2.10)	49 (1.69)	11 (1.04)	4 (0.60)	9 (0.95)
Mean	111(1.96)a	58(1.68)b	13(1.01)c	4(0.67)d	11(1.01)c
P Level treat	0.44(0.18)	<0.001(0.003)	0.74(0.15)	0.59(0.76)	0.57(0.35)
LSD	ns (0.33)	38(0.29)	ns(0.32)	ns(0.30)	ns(0.30)
CV	8.2	8.8	9.3	15.1	19.8
P Season			<0.001		
Treatment X season			0.65		
Mean season	3.39	3.10	2.46	1.98	2.38

‘LR=long rainy season, ‘SR=short rainy season, CC=*Calliandra*, MS =maize stover, U=urea,

Effect of treatments on maize grain yield components

Ear traits

The effect of treatments and seasons on the number of ears per plant, ear length, and ear diameter were highly significant (p<0.001) (Table 5). Treatments X season interactions were not significant for any of these ears traits (Table 4). All the three ear traits (ears per plant, ear length, and ears diameter) were significantly higher where Calliandra was applied (45 kg N ha^{-1}) combined with urea (30 kg N ha^{-1}) and Calliandra (30 Kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) or maize stover (45 kg N ha^{-1}) combined with urea (30 kg N ha^{-1}) and maize stover (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) compared to sole maize stover and the control. Ears per plant were highest where maize stover was applied (30 kgN ha^{-1}) combined with urea (45 kg N ha^{-1}), while the lowest ears per plant were recorded in the control. Ear length and ear diameter followed the same trend. Sole maize stover had the lowest ear diameter. Although ears per plant are known to be a genetically controlled characteristic this trait was influenced by the amount of nutrients available. The higher ears per pant where maize stover was applied at (30 kgN ha^{-1}) combined with urea (45 kg N ha^{-1}) is mainly attribute to higher mineral N levels in the soil. The low ears per plant in sole maize stover and the control may be as a result of low levels of soil mineral N. Low numbers of ears per plant may also be attributed to higher Striga numbers in the control and sole maize stover treatments (Table 5). Ear reduction from pre-flowering stress results from cessation of ear development and ear abortion (Jacobs and Pearson, 1991). This is in contrast to insidious and more delayed pathogenic effects, which have little or no effect on ears per plant (Kim and Brewbaker, 1976).

The significantly higher ear length in the above soil fertility management applications might be attributed to good photo assimilates supply. The maximum assimilate supply should be available during maize grain filling (Arif *et al*., 2010). The two to three weeks period after 50 % silking is critical stage in the development of maize that is highly dependent on assimilate supply; the period when final kernel number is determined (Haney *et al*., 2015). Hussaini, *et al*. (2001) reported similar response where they attributed this significant increase in yield to favorable effect of N on cob length and cob diameter, which have direct bearing on the final grain yield.

Table 5. Mean grain yields and yield components of maize under *Striga* infestation averaged over five seasons at Nyabeda

Treatment	**Ears/ plant**	**Ear length (cm)**	**Ear diameter (cm)**	**Kernel Rows**	**Kernels/ Row**	**100 wt (g)**	**Grain Yield (g/plant)**	**Striga tolerance Score (1-9)**
Control	0.56	13.3	4.0	13.0	26.9	24.5	24.0	6.6
75CC+0U	0.77	15.1	4.2	13.2	27.5	27.1	45.0	2.8
60CC+15U	0.64	14.6	4.3	13.4	30.8	25.3	37.1	3.6
45CC+30U	0.79	15.4	4.2	13.1	33.4	25.8	54.0	2.4
30CC+45U	0.79	15.4	4.3	13.7	32.2	25.6	48.5	2.6
15CC+60U	0.76	14.6	4.2	13.4	31.7	26.2	41.9	4.1
75MS+0U	0.64	13.3	3.9	12.3	27.4	22.9	30.5	4.5
60MS+15U	0.71	14.2	4.1	13.4	30.1	23.9	37.1	4.7
45MS+30U	0.80	15.1	4.3	13.1	32.6	25.1	50.0	3.0
30MS+45U	0.82	16.1	4.4	13.2	35.0	28.7	59.9	2.6
15MS+60U	0.76	15.2	4.3	12.9	33.4	27.1	45.4	3.4
75U	0.70	14.5	4.2	12.9	30.6	25.9	39.7	3.9
Mean	0.73	14.7	4.2	13.1	31.4	25.7	42.8	3.7
P treat	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	<0.001	<0.001
P season	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
P treat x season	0.184	NS	0.135	0.29	0.277	NS	0.002	NS
Lsd treat	0.108	1.14	0.16	0.72	3.27	2.15	11.0	1.62
lsd season	0.06	0.66	0.09	0.42	1.89	1.24	6.37	
lsd treat x season	0.21	2.28	0.31	1.44	6.55	4.30	22.05	
CV	7.0	3.0	2.5	2.2	3.7	1.5	13.3	20

Kernel traits and grain yields

Number of grains per row

There were highly significant differences ($p<0.001$) between season and treatments kernels per rows (Table 5). The highest kernels per rows was recorded where maize stover was applied at (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}), while the lowest was recorded in the control. Kernels per ear are a product of rows per ear and kernel per row (Abendroth *et al*., 2011). Rows per ear have been reported to be largely genetically controlled (Roy and Biwas (1992), and ear length to be highly correlated with kernels per row as observed in earlier studies (Bavec and Bavec 2002). However, a greater number of grains per ear observed under higher N rates might have resulted from the greater assimilates partitioning to the seeds as a result of a longer growth period and higher photosynthate availability during grain filling period (Amanullah *et al*., 2009). A decrease in number of grains per ear row under low N application might be attributed to poor development of the sinks and reduced translocation of the photosynthate (Dawadi and Sah, 2012).

Grain yield

Grain yields and 100-grain weight were optimized where Calliandra was applied (45 kg N ha^{-1}) combined with urea (30 Kg N ha^{-1}) and Calliandra (30 Kg N ha^{-1}) combined with urea (45 Kg N ha^{-1}) or maize stover (45 Kg N ha^{-1}) combined with urea (30 Kg N ha^{-1}) and maize stover (30 Kg N ha^{-1}) combined with urea (45 Kg N ha^{-1}) This is mainly attributed to high mineral N levels in the soil. Higher N content facilitates chlorophyll formation, photosynthesis, assimilate production and higher partitioning of dry matter to ears that resulted in optimum production of yield components which have direct bearing on the final grain yield. Hussaini, *et al*. (2001) reported similar response. The increase in yield could be as a result of high dry matter production for grain filling as a result of higher number of leaves.

The low grain yields in sole maize stover treatments and the control could be attributed to low mineral nitrogen levels. Low quality organic materials such as maize stover with high C/N ratio take long to decompose and release N, leading to N immobilization (Palm *et al*. 2001). Low maize yields may also be attributed to high levels of Striga infestation under these treatments, which result from a series of physiological changes in the host plants. These include weakening of the host, wounding of its outer root tissues and absorption of moisture, photosynthates and minerals (Tenebe and Kamara, 2002). Apart from parasitism, Striga impairs photosynthetic efficiency (Stewart *et al*., 1991) and exerts toxic or phytotoxic effects (Gurney *et al*., 2006).

Relationship between maize grain yield and yield components

All yield components except ear length and kernel rows were significantly ($p<0.1$-0.001) correlated with grain yields (Table 6). However the degree of association for the various yield components was dependent on season. Correlations were strong in the long rain seasons than the short rain seasons. Ears per plant showed the highest correlation with grain yield ($r = 0.76$, $p<0.001$). Similar observations were also made by Jugenheimer, (1985). The increase in grain yield is could be attributed to beneficial influence of yield contributing characters and positive interaction of nutrients in the blended fertilizer. The strong relationships found between grain yield, number of kernels per row and hundred kernels weight were in agreement with other e findings (Elings *et al*., 1996, Khatun *et al*., 1999).

Table 6. Correlation coefficient (r) between grain yields and yield components

Yield component	**Season**					**Overall**
	LR2007	**SR2007**	**LR2008**	**SR2008**	**LR2009**	
Ears per plant	0.80***	0.60***	0.84***	0.55***	0.38**	0.76***
Ear length	0.75***	0.38*	0.43**	0.28*	0.55***	0.37
Ear diameter	0.46***	0.40**	0.52***	0.35*	0.038**	0.39***
Kernels/row	0.05	0.45**	0.37**	0.47**	0.51***	0.48
Kernel rows	0.68***	0.20	0.36*	0.16	0.50***	0.62***
100-kernel weight	0.63***	0.10	0.46**	0.06	0.39**	0.37**

* denotes significance at 0.1, ** at 0.05 and *** at 0.01. LR and SR are long and short rains respectively.

Table 7. Regression equations relating yield components (X) to grain yield (Y) under *Striga* and coefficients of determination

X_1	**Regression equation**	**S.E.**	R^2
Ears/plant	$Y= -11.31 + 74.29X_1$	4.54	58.55
Ear diameter	$Y= -52.68 + 22.58X_2$	3.91	14.95
Kernels/row	$Y= Y= -33.73 + 2.43X_3$	0.22	38.95
100 kernel weight	$Y= -42.27 + 3.31\ X_4$	0.34	33.17

$Y= -86.10 + 58.05X_1 + 9.27X_2 + 0.54X_3 + 1.188X_4$; $R^2=72.41\%$

Stepwise regression analysis showed ears per plant to be the most important yield component under Striga infestation, followed by kernels per row (Table 7). This indicates that yield differences under Striga could be explained by variation in ears per plant and kernels per row. The proportion of yield variation accounted for by ears per plant shows that this trait was a major yield component under Striga, and it could be useful as a selection index.

Conclusion and recommendations

All the three ear traits: ears per plant, ear length, and ears diameter, were significantly higher where Calliandra was applied at 45 kgN ha^{-1}) combined with urea (30 kg N ha^{-1}) and Calliandra at (30 Kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) or maize stover (45 kg N ha^{-1}) combined with urea (30 kg N ha^{-1}) and maize stover at (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}). Early and consistent supply of nitrogen is critical for production of maize under Striga infested conditions. Number of ears per plant was a major yield component with $R^2 = 0.74$. Ears per plant and kernel per row were the most important traits that influence grain yield under *Striga.*

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The Incidence, Severity and Characterization of Botryosphaeriaceae fungi on *Melia volkensii* Guerke and *Azadirachta indica* A. Juss. Trees in Kenya's Arid and Semi-arid Lands

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Abstract

The *Botryosphaeriaceae* fungal family has been found to be of economic importance in forest plantations and trees planted on farms worldwide. In Kenya, the family has been reported on *Grevillea robusta* on-farms across all agro-ecological zones. Being an endophyte, *Botryosphaeriaceae* are known to become pathogenic at the onset of stress. Two *Meliaceae* tree species, *Azadirachta indica (*A. Juss.*)* and *Melia volkensii (*Geurke*)* in natural stands and on-farm were sampled and analyzed for potential pathogens across the dryland forests of Kenya. The objective of the study was to determine the incidence, severity and characterization of Botryosphaeriaceae fungi associated with *M. volkensii* and *A. indica* trees in selected parts of Arid and Semi-arid Lands (ASALs) of Kenya using laboratory analysis techniques. Incidence and severity were determined by assessing lesions on individual trees and counting those affected per farm. Laboratory isolations categorized frequent pathogens as: *Botryosphaeriaceae* (53%), *Nectriaceae* (34%) and *Pestaloptiosis* (9%). *Botryosphaeriaceae* was more prevalent in *Melia volkensii* with a mortality rate of 28% than *Azadirachta indica* (16%). DNA results of the ITS and EF1-α gene regions for 86 isolates were sequenced into 6 species of the *Botryosphaeriaceae*. 4 of the species belonged to the genus *Lasiodiplodia* namely *L. pseudotheobroma, L. pseudotheobromae, L. theobromae* and *L. parva*. This is the first report of *Botryosphaeriaceae* on these tree species and the first report of species *Spencermartinsia viticola* and *Macrophoma theicola* in Kenya. Pathogenicity tests done under glass house conditions showed that wilting, necrosis, gummosis and lesion development was recorded within 7 days of seedling inoculation but wound healing occurred on both species by the end of 12 weeks. These characteristics are required in tree species recommended for effective climate change mitigation and adaptation strategies. It also unveils wider host diversity for the fungal family globally necessitating the need to develop effective pest management strategies for climate change mitigation and adaptation to protect forests.

Keywords: Botryosphaeriaceae, meliaceae, disease tolerance

Introduction

The family Botryosphaeriaceae Theiss & P.Syd. is a family of fungi with a cosmopolitan distribution across the globe except in the Polar regions. Species of the Botryosphaeriaceae have been classified as pathogens, endophytes and also saprobes (Slippers and Wingfield, 2007). The family cannot be classified as latent pathogens due to the pathogenic nature of some of the species (Liu *et al*., 2012). Symptoms associated with this fungal family include: die-back and wilting of twigs and branches, longitudinal cankers on stem and twigs, girdling of stems by canker and sunken holes on the bark (Pitt *et al.,* 2010). Signs of infection include presence of pycnidia on the surface of the stem (Slippers *et al*., 2009). The fungus overwinters as pycnidia and is disseminated by wind and rain splash from branch to branch when the weather is warm and humid (Sinclair and Lyon, 2005). Mode of infection is through wounds caused by pruning or mechanical damage and natural openings such as stomata and lenticels (Njuguna *et al*., 2011). The conidia enter the wood through such wounds and openings then germinate and affect the surrounding wood where they cause stem rot and lesions (Phillips *et al*., 2013; Slippers *et al*., 2007).

Melia volkensii Gürke and *Azadirachta indica* A. Juss. trees of the family Meliaceae are among the useful trees and shrubs in Kenyan ASALs (Vandenabeele, 2015; Maundu and Tengnas, 2005; Mulatya and Misenya, 2005). The two tree species are drought tolerant; perform well on poor soils in tropical Africa, especially in arid and semi-arid regions including Kenya (Muok *et al*., 2010). *Melia volkensii* is useful in the ASALs for the provision of timber, fuelwood and bee forage. It is fast growing and produces quality timber in about 10 years (Kariuki *et al*., 2007). *Azadirachta indica* is useful as a source of herbal medicine, oil and insecticide extracts. Despite the fact that extracts of various organs (e.g. leaves, stem, roots and bark) of *A. indica* have fungicidal and antibacterial ingredients, certain pathogens are able to attack the tree (Infornet Biovision, 2017; TNAU, 2016). A pathogenicity test under glass house conditions using species of *Botryopshaeria* isolated from *Grevillea robusta* in Kenya revealed that *A. indica* seedlings were susceptible to the fungi (Njuguna *et al*., 2011). However, whether the seedlings and mature trees in the open are susceptible to *Botryosphaeria* is yet to be determined.

Incidences of canker on *A. indica* and *M. volkensii* trees have recently been reported in some parts of the drylands of Kenya (Njuguna *et al*., 2005; pers. comm.). In addition, there is evidence that fungi of the family Botryosphaeriaceae are causative agents of canker and dieback in a number of trees in Eastern Africa, such as *Grevillea robusta* and *Eucalyptus* spp. (Toljander *et al*., 2007; Gezagne *et al*., 2004). Exact identification of the pathogens is a prerequisite to the prescription of their management and control. The aim of the study was to determine the incidence, severity and characterization of Botryosphaeriaceae fungi associated with *M. volkensii* and *A. indica* trees in selected parts of Arid and Semi-arid Lands (ASALs) of Kenya.

Materials and Methods

This study was carried out in selected eight ASAL counties in Kenya that lie within agroecological zones (AEZ) IV and V as described by Jaetzold and Schmidt (1982) Figure 1. The counties were: Kitui and Kibwezi (where there are many woodlots and natural populations of Melia trees), Kilifi, Kwale, Voi and Lamu (where there are natural populations and woodlots of both tree species), Mbeere and Tharaka Nithi (where there are many trees of both *M. volkensii* and *A. indica* both on-farm and in the wild. The eight counties are located in three major geographical areas of the country: Coast, Upper Eastern and Lower Eastern as detailed in Table 1.

Table 1. Location of the eight ASAL counties in Kenya, where the study sites were located

No.	County	Location		Reference
		Longitude	Latitude	
1.	Kitui	37 50’ and 39^0 00’ East	0^0 10’ and 3^0 00’ South	GoK, 2015a
2.	Kibwezi (Makueni)	37^0 10’ and 38^0 30’ East	1^0 35’ and 3^0 00’ South	GoK, 2013a
3.	Kilifi	39^0 05’ and 40^0 14’ East	2^0 20’ and 4^0 00’ South	GoK, 2013b
4.	Kwale	39^0 23’ and 39^0 30’ East	3^0 45’ and 3^0 55’ South	GoK, 1974
5.	Voi (Taita Taveta)	37^0 14’ and 37^0 36’ East	2^0 46’ and 4^0 10’ South	GoK, 2014a
6.	Lamu	40^0 15’ and 40^0 35’ East	1^0 40’ and 2^0 30’ South	GoK, 2014b
7.	Mbeere (Embu)	37^0 03’ and 37^0 09’ East	0^0 08’ and 0^0 50’ South	GoK, 2016
8.	Tharaka Nithi	37^0 19’ and 37^0 46’ East	0^0 07’ and 0^0 26’ South	GoK, 2015b

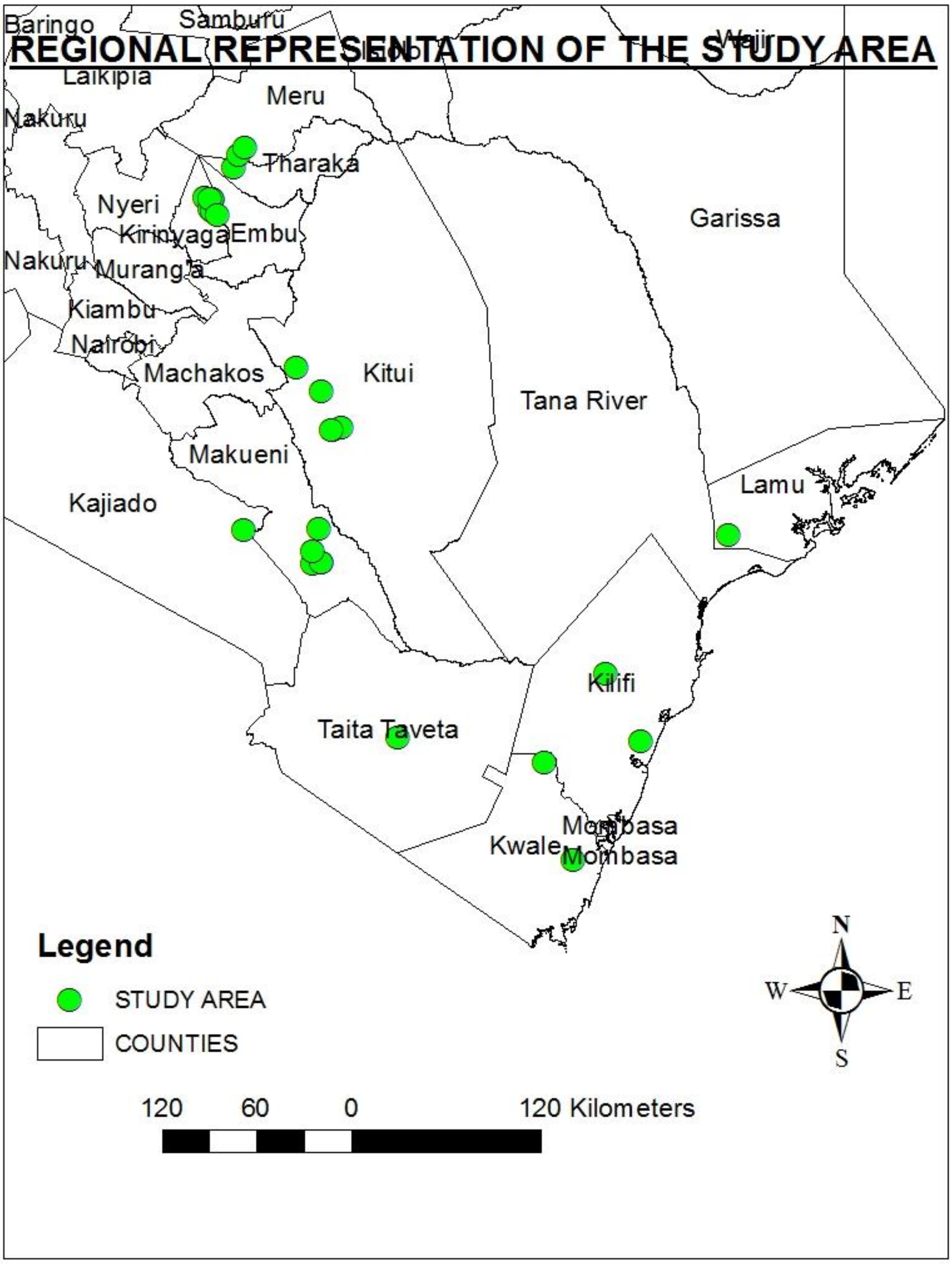

Figure 1. Map showing the study area

The general climatic characteristics of the sites where the study was carried out are as follows: Bi-modal mean annual rainfall that is below 500 mm occurring in two seasons March - May and October - December; prolonged dry periods and high mean temperatures of 23 - 24 ^{0}C (Jaetzold and Schmidt, 1982; UNDP, 2013; GoK, 2012). Soils in the study sites were predominantly sandy with variations of sandy loam classified as lithosols, regosols and xerosols with low to very low fertility (Infornet Biovision, 2017b; Gachene and Kimaru, 2003).

Multistage sampling was used in this study (Dudovskiy, 2016; Holdenrieder *et al*., 2015). Four clusters of each tree species were randomly selected at each site. Symptoms observed in each cluster and on each tree were recorded and samples from stems, leaves and branches collected for fungal isolations in the laboratory.

The fungi were isolated using the standard methods described by Njuguna *et al*., (2005). Once a pure culture was obtained, morphological characteristics were used to group the fungi into their genera. Colony and spore characteristics were also studied according to Barnette and Hunter (1972). Conidial morphology helped to group fungal species together for easier selection of isolates for further identification using DNA based methods.

DNA was extracted from a single spore culture of the isolated fungi for use in characterization of pathogens. The CTAB method as described by (Phillips *et al*., 2013) was used in extracting DNA from fungal mycelia. The pellets were then washed with Sodium Chloride and the DNA quantified before performing Polymerase Chain Reactions (PCR). PCR products were purified using the Sephadex® 50.0 Purification Kit and gel electrophoresis done using Agarose gel for the PCR products. Purified products were then run on ABI PRISM® 310 Sequencer machine using Big Dye ® and the nucleotide sequences were downloaded and edited to FASTA format. The downloaded sequences are first aligned using special programming language (e.g. ClustalW) then compared with existing sequences from Genbank and other culture collections to find the closest relative at 100 %. The relationship was analyzed using Mega v. 7.0 Software (Tamura *et al*., 2015) to produce a cladogram to further analyze relationships between the isolates using the neighbour-joining method described by (Saitou and Nei, 1987).

Pathogenicity tests were done in accordance with Yang (2015) and Fichera (2009) and run for 12 weeks. Symptoms developed were recorded and at the close of the experiment the lesions were measured and lab re-isolations carried out.

Results

The results showed that most isolated fungal family was Botryosphaeriaceae, which made up to 53 % of the total number of isolates as grouped using conidial morphology. Nectriaceae, which are also associated with leaf diseases and dieback and were second in abundance at 34

% of the total population. Other fungal genera isolated included *Alternaria* spp., *Phoma* spp., and *Phomopsis* spp. whose combined frequency was 4% of the total.

Table 2. Fungal frequencies

Fungal Family	**Frequency**	**% of the total**
Botryosphaeriaceae	125	53
Nectriaceae	81	34
Amphisphaeriaceae	22	9
Others	10	4
Total	**238**	**100**

The fungi isolated were taken through DNA analysis for species level identification. The results were compared with existing databases and the data tabulated below showing the fungus name, and the sequence length in base pairs. Their accession numbers at Genbank and NCBI databases are also indicated in Table 3.

Table 3. The Internal Transcribed Spacer (ITS) and Trans elongation factor Tef 1 alpha DNA regions

Accession Number for Tef 1 alpha and ITS	**Fungus Name**	**Length**
KC964548	*Lasiodiplodia theobromae* isolate 81.I	565bp
JX914479	*Lasiodiplodia pseudotheobromae* isolate 7 DL5-2	561bp
KC623566	*Lasiodiplodia sp. (L. pseudotheobroma*)	534 bp
FJ904841	*Lasiodiplodia theobromae* strain Gr42B	558bp
KP179222	*Macrophoma theicola* strain UPA-62	1656 bp
KM406107	*Lasiodiplodia theobromae* voucher MAC Karu-4	565 bp
GQ469964	*Lasiodiplodia parva* strain CMW28295	563 bp
GU799456	*Lasiodiplodia crassispora* strain UCD24Co	527 bp
KJ528885	*Talaromyces purpureogenus* strain ZB076	574 bp
KP271958	*Alternaria alternata* strain 9C	556 bp
JF271752	*Spencermartinsia viticola* strain UCP134	780 bp
GQ469961	*Lasiodiplodia parva* strain CMW28333	572 bp
EU918710	*Lasiodiplodia crassispora* strain xsd08010	567 bp
KP004441	*Macrophoma sp.* VPM-12	1639 bp
FJ478103	*Lasiodiplodia theobromae* strain xsd08007	567 bp
GU799458	*Diplodia corticola* strain CBS678.88	412 bp
KF777137	*Alanphillipsia aloeigena* strain CPC 21286	697 bp
KM006447	*Lasiodiplodia pseudotheobromae* strain B0361	545 bp
EU497954	*Penicillium griseofulvum* strain F22	578 bp
KF766192	*Lasiodiplodia parva* strain CBS 456.78	551 bp
KP120986	*Pestalotiopsis sp*. PG52	602 bp
JX914481	*Fusarium solani* isolate 9 EL1-4	554 bp
KJ190278	*Neofusicoccum parvum* isolate A564	539 bp
JF819161	*Nigrospora sp*. TA26-42	533 bp
FJ867936	*Fusarium oxysporum* strain LCF32	1164 bp
KF746102	*Cytospora sp.* 1 AE-2013 strain F4839	600 bp
KJ197289	*Diaporthe macintoshii* strain BRIP 55064a	704 bp
LN809047	*Penicillium chrysogenum*	579 bp
KF624777	*Curvularia sp.* RIFA 73B	606 bp

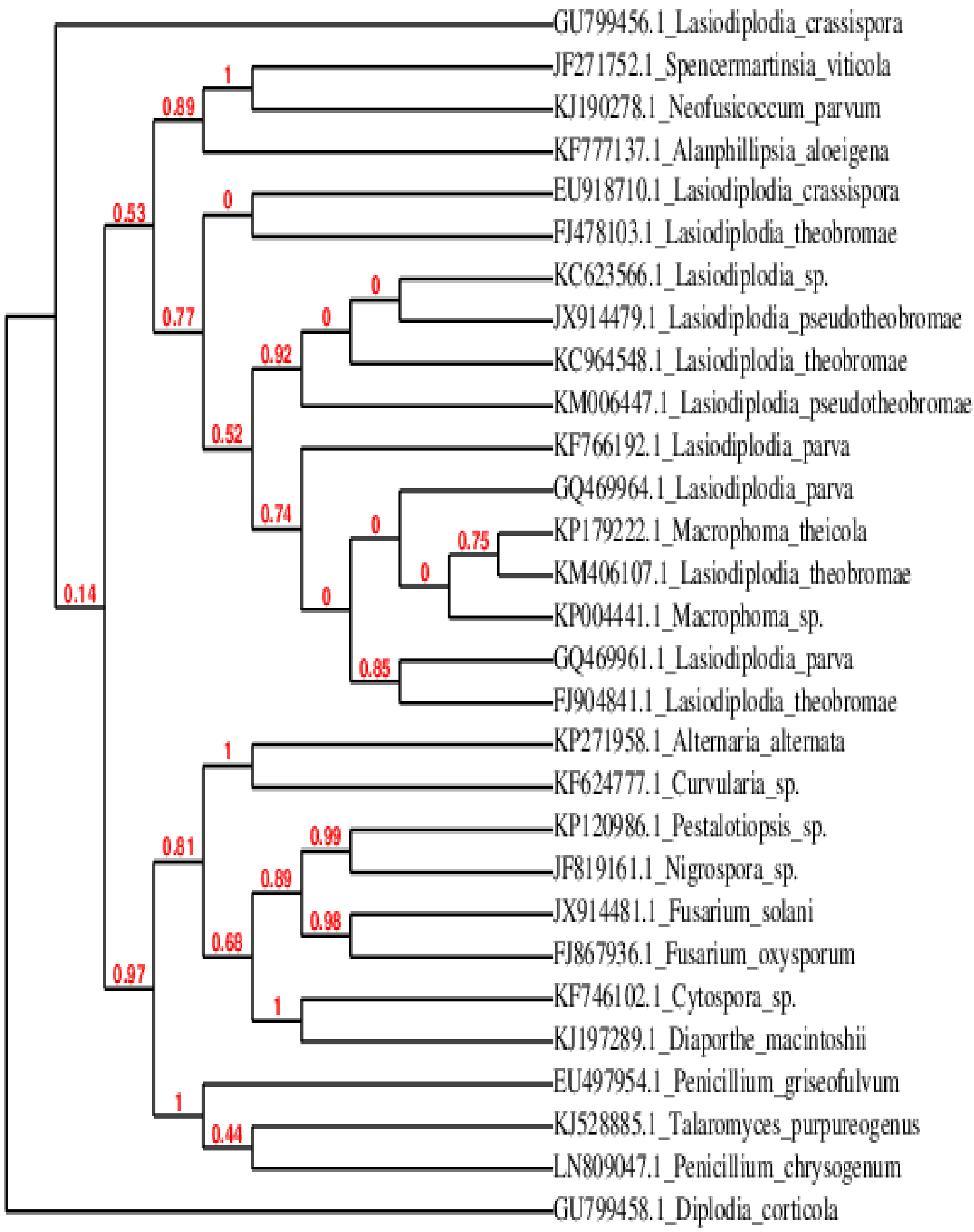

Figure 2. Cladogram showing the relationships between fungi isolated using the neighbour-joining method

Discussion

The study revealed that in addition to the commonly known fungi, some of the fungi isolated namely *Spencermartinsia viticola* and *Macrophoma vitricola* have not been found before in the country. Predisposing factors recorded in the field including poor pruning practice, termite damage and presence of parasitic plants led to higher disease incidence and severity.

Species of Botryosphaeriaceae have been found on other native *Fabaceae* and *Myrtaceae* in South Africa, Venezuela and India (Slippers *et al*., 2009; Ismail *et al*., 2012). The presence of *Neofussicoccum parvum, Lasiodiplodia theobromae* and *L. pseudotheobromae* in this study, as well as on the *Grevillea robusta* (Njuguna *et al.,* 2011) presents a possibility of spread from one species to the other. However, the incidence levels were lower due to the ability of the indigenous species to withstand drought hence less cases of disease from *Botryosphaeriaceae* family, which have been classified as latent pathogens that attack on the onset of stress.

Meliaceae as a family has been studied on a limited scale on its pest-repellant properties. *Botryosphaeriaceae* species with their characterization as endophytes and/or latent pathogens have a cosmopolitan distribution and keep increasing their host range as climatic conditions keep becoming more detrimental to plants in the field. Latent pathogens are present in healthy plant systems and only become pathogenic at the onset of stress.

For both *Melia volkensii* and *Azadirachta indica* the initial response as seen in the glass house experiments was chlorosis followed by wound healing of the seedlings. The presence of phenolic compounds in this plant family could explain their perceived resistance and healthy condition despite high percentage of the severity and incidence in the field.

Conclusion

For possible mass planting of these species in the ASALs technical orders need to amend to include closer management pruning and thinning with bigger spacing for root development to aid in water absorption as well as regular weeding to reduce competition for increased survival.

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Preliminary Results on Optimal Spacing and Pruning Regimes of *Melia volkensii* in the Drylands of Kenya

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Abstract

Melia volkensii is an important tree in the drylands of Kenya because of its high economic value and termite resistant timber. Melia is also a fast growing usually acquiring good form when properly managed. However, if not appropriately managed, Melia trees can become bushy with short boles, unsuitable for timber production. Spacing and pruning trials were therefore established to inform on appropriate spacing and pruning practices to support growing of Melia. The design used was randomized complete block with five treatments replicated three times at a spacing of 3 m x 3 m, 4 m x 4 m, (with normal pruning), 4 m x 4 m, (with total pruning), 5 m x 5 m and 6 m x 6 m. The trial was replicated in Mutomo and Kibwezi. Results of eight years after planting showed a significant difference in height growth in all the treatments at both sites. The wide spacing of 6 m x 6 m favoured height, diameter at breast height and crown diameter growth. The study recommends that future measurement be used to quantify the volume of timber for all the treatments as part of the efforts of prescribing appropriate silvicultural treatment for the species.

Keywords: *Melia volkensii*, spacing, height, diameter at breast height (dbh) and crown diameter

Introduction

Melia volkensii (Melia) is an important tree in the drylands of Kenya due to its high economic value, and termite resistant timber (Mulatya *et al*., 2002). A survey in Mbeere District indicated that farmers also treasure the species as animal fodder (Kidundo, 1997). The species characteristics and multipurpose nature have accelerated Melia planting on farmlands. Early successes in establishment and good performance of Melia have consequently increased its growing on a large scale and in plantations. Extensive planting of the species started in the late 1990s in Kitui and Kibwezi areas. Growth of Melia in well managed plots in the arid areas is reported to exceed that of other indigenous tree species within the drylands (Kimondo 2002; Mulatya and Misenya, 2006).

Generally, farmers believe Melia has no negative effects on crops when intercropped. In the past, these anecdotal were made by pioneers of agroforestry who advocated positive tree - crop interaction based on the trees' ability to recycle nutrients. However, scientific evidence indicates that there is some negative tree - crop interaction because of above- and below-ground competition (Mulatya *et al.*, 2002). The scarce soil moisture in the drylands due to low erratic rainfall, as well as poor soils, remains a major challenge and limit tree planting. One way to overcome these challenges is to adopt management that allows better tree growth such as increased espacement. However, currently there are no clearly defined management regimes, particularly spacing and pruning systems that be recommended for on farm tree growing or plantation establishment.

It has been documented that Melia has rapid growth usually acquiring good form when properly managed (Mulatya, 2000). However, if not properly managed, the trees can become bushy with short boles, unsuitable for timber production. Spacing and pruning trials were therefore established with the main objective of determining the appropriate silvicultural practices to support growing of Melia in plantations. The specific objectives of the trial were:

- To determine the optimal spacing for growing *Melia volkensii*
- To determine the pruning regimes for *M. volkensii*

Materials and Methods

Melia seedlings were raised in Tiva tree nursery and planted in Mutomo in Kitui County and Kibwezi in Makueni County. Both sites experience bimodal rainfall pattern with a mean annual precipitation of 1038 mm in Mutomo and 630 mm in Kibwezi. The wet months are March to May, considered the long rains and mid-October to December which is considered the short rains with a peak in November. Tree planting is carried out in November rain mainly because the dry period preceding the next rains is shorter (2 months) than if planting was done during the long rains where the dry period before the peak of the next rain is about 6 months. The mean maximum temperatures range is between 20^{o}C to 30^{o}C, while the minimum values range between 15^{o}C to 17^{o}C.

The planting sites were oxen ploughed and staking and pitting carried out before the onset of rains. The design used was a randomized complete block design with 5 treatments replicated three times at a spacing of 3 m x 3 m, 4 m x 4 m with normal pruning (NP), 4 m x 4 m with total pruning (TP), 5 m x 5 m and 6 m x 6 m. Weeding was done in the first, second and third month after planting. Thereafter weeding was carried out twice annually (i.e. after the short and long rains). Pruning was done through removal of auxiliary buds in the second, third and fourth month after planting. Thereafter pruning was carried out twice annually (i.e. after the short and long rains). The parameters measured were total height, diameter at breast height (dbh) and crown diameter. In this paper we report on data collected at ages 2, 3, 4, 5, 6 and 8 years. Statistical Analysis of Variance and calculation of means were carried out using Genestat 16th edition.

Results

Height

There was significant difference in height growth in all the treatments in both Mutomo and Kibwezi sites Eight years after planting. Height growth in the 3 m x 3 m spacing was lowest compared to other spacing treatments (Figures 1a and 1b.)

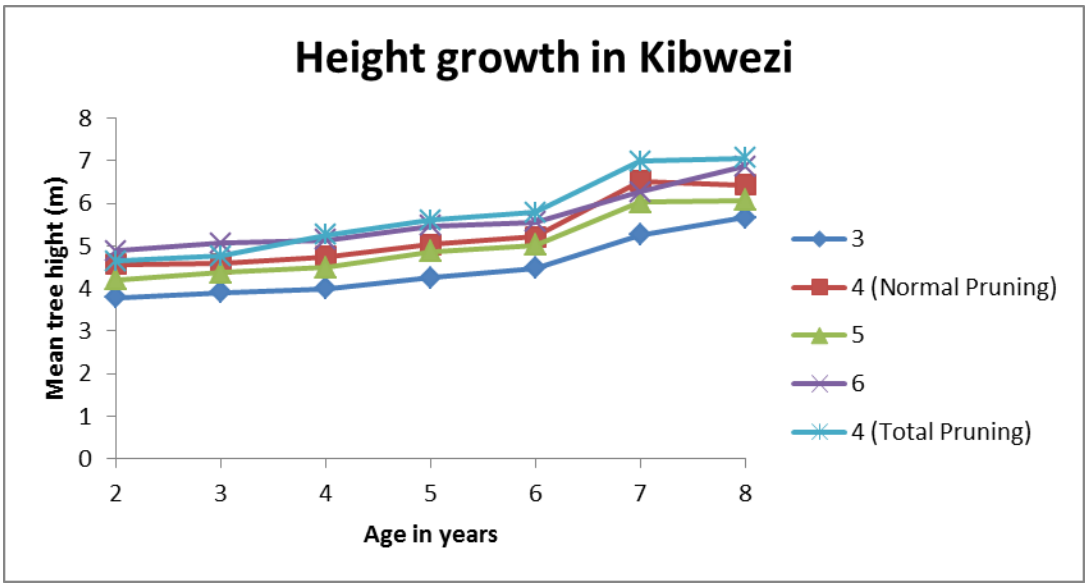

Figure 1a. Height growth trend in Kibwezi site

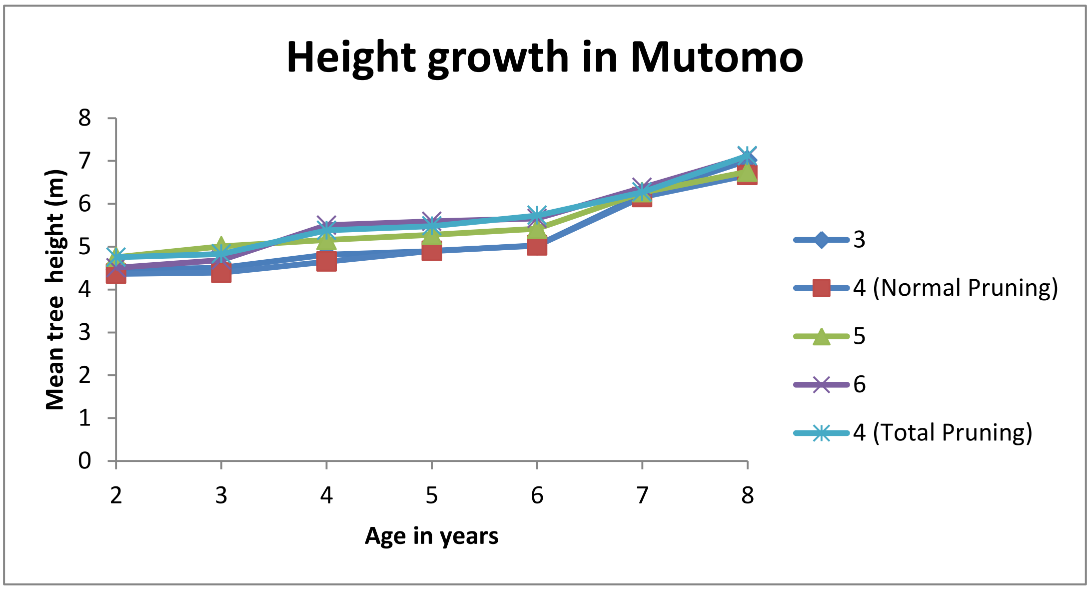

Figure 1b. Height growth trend in Mutomo site

Table 1. Varatiate: Mean Height (m)

Site	Spacing	Mean	S.E	Confidence Interval
Mutomo	3m x 3m	5.275a	0.3634	5.275±0.3634
	4m x4m (Normal Pruning)	5.166a	0.3392	5.166±0.3392
	5m x 5m	5.517a	0.2724	5.517±0.2724
	6m x 6m	5.63a	0.3417	5.63±0.3417
	4m x4m (Total Pruning)	5.652a	0.3136	5.652±0.3136
	p value			0.778
	L.S.D			0.946
Kibwezi	3m x 3m	4.474a	0.2724	4.474±0.2724
	4m x4m (Normal Pruning)	5.301ab	0.3172	5.301±0.3172
	5m x 5m	5.008ab	0.2897	5.008±0.2897
	6m x 6m	5.607ab	0.2705	5.607±0.2705
	4m x4m (TotalPruning)	5.729b	0.369	5.729±0.369
	p value			0.048
	L.S.D			0.884

Diameter at breast height

The diameter at breast height increased drastically for the two sites overtime. In the fifth year very small magnitude of change was recorded. Diameters for Mutomo site were higher than those of Kibwezi (Figures 2a and 2b.)

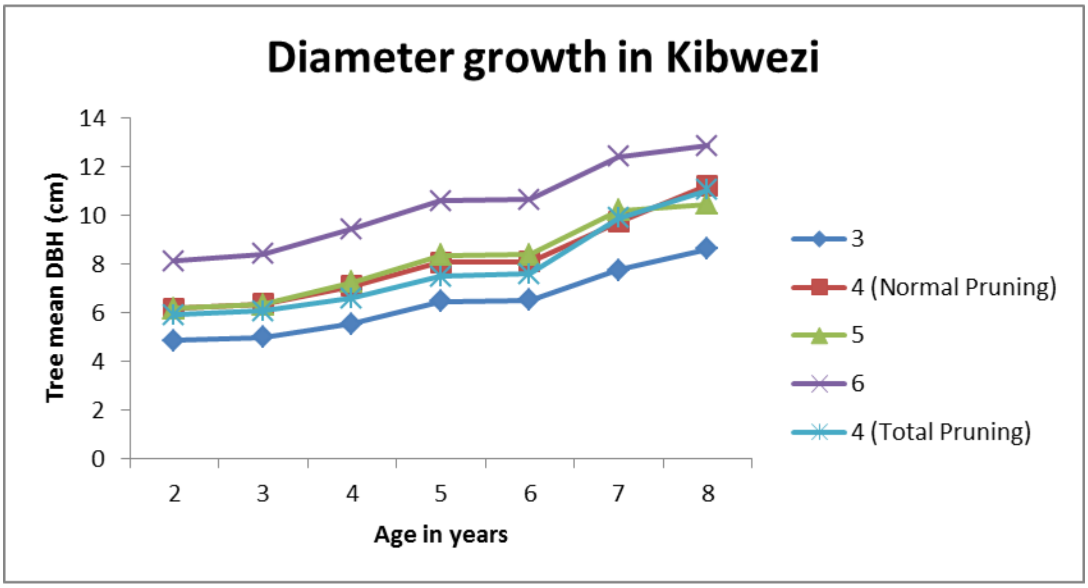

Figure 2a. Diameter at breast height growth trend in Kibwezi site

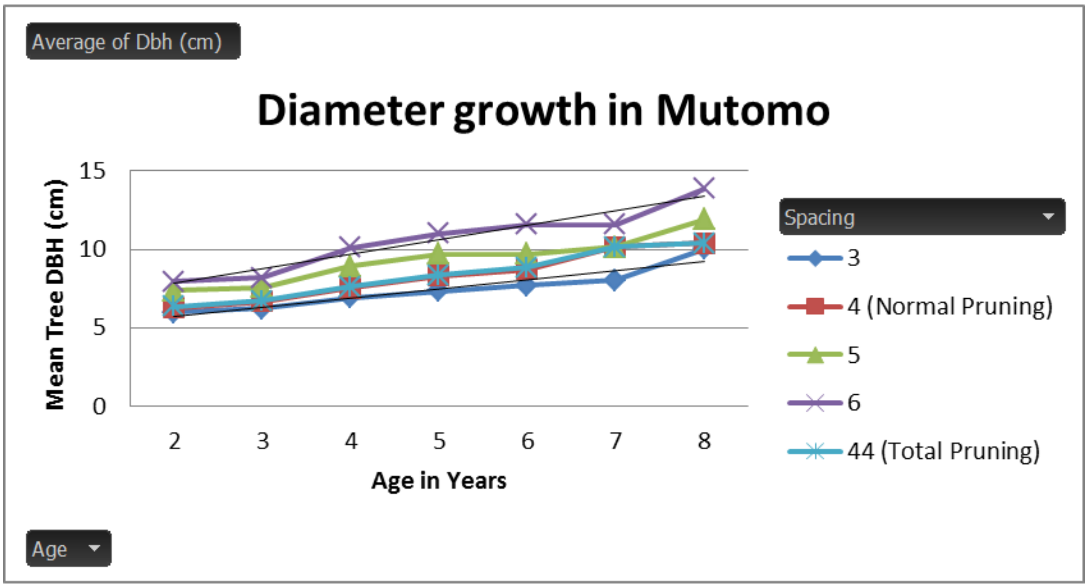

Figure 2b. Diameter at breast height growth trend in the Mutomo site

Testing the significance differences between the different spacing

ANOVA was used and significance tested at 95% level. There was a significant difference between the different levels of spacing ($p=0.014<0.05$, for Mutomo site; $p=0.05$ for Kibwezi site)

Table 2. Varatiate: Mean dbh (cm)

Site	Spacing	Mean	S.E	Confidence Interval
Mutomo	3m x 3m	7.456a	0.509	7.456±0.509
	4m x4m (Normal Pruning)	8.29ab	0.6032	8.29±0.6032
	5m x 5m	9.329ab	0.5902	9.329±0.5902
	6m x 6m	10.611b	0.7839	10.611±0.7839
	4m x4m (Total Pruning)	8.343ab	0.595	8.343±0.595
	p value			0.014
	L.s.d			1.799
Kibwezi	3m x 3m	6.397a	0.5336	6.397±0.5336
	4m x4m (Normal Pruning)	8.111ab	0.6936	8.111±0.6936
	5m x 5m	8.175ab	0.6489	8.175±0.6489
	6m x 6m	10.36b	0.6938	10.36±0.6938
	4m x4m (Total Pruning)	7.801ab	0.7413	7.801±0.7413
	p value			0.005
	L.S.D			1.924

Crown diameter

There was significant difference in crown diameter for all the treatments in both sites from two years to the fifth year after planting. Crown width showed a gradual increase with spacing for all the treatments (Figure 3a and b).

Tree crown cover (cm) Kibwezi

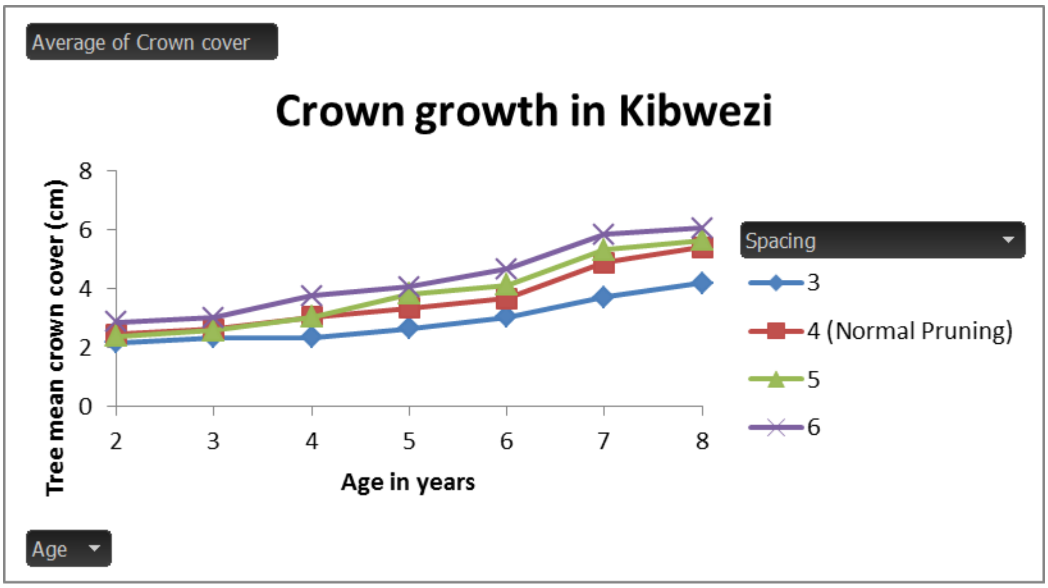

Figure 3a. Crown diameter trend in Kibwezi site

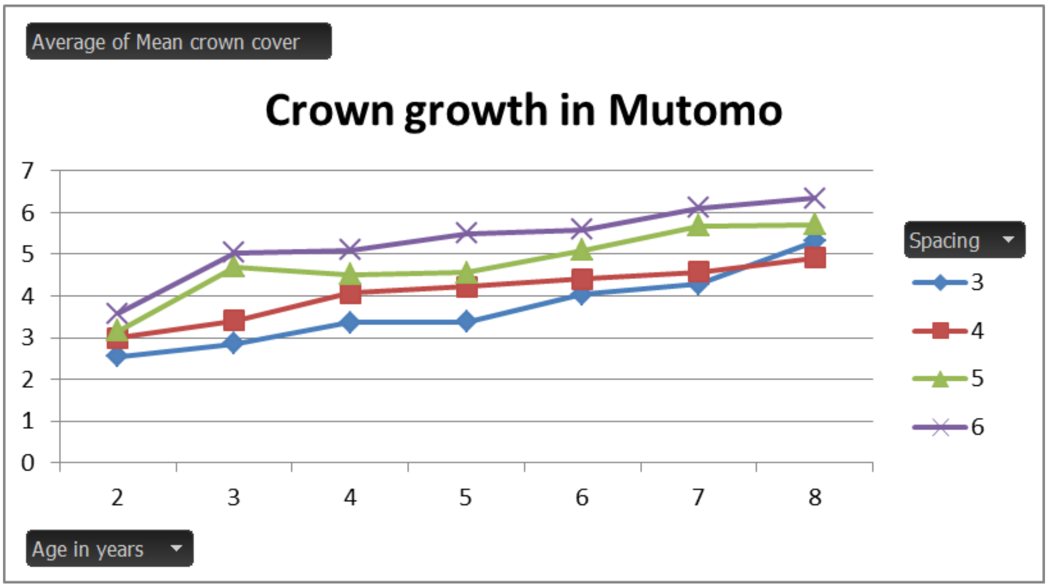

Figure 3b. Crown diameter trend in Mutomo site

Varatiate: Mean Crown cover (cm)

Site	Spacing	Mean	S.E	Confidence Interval
Mutomo	3m x 3m	3.683a	0.3557	3.683±0.3557
	4m x4m (Normal Pruning)	4.083ab	0.2549	4.083±0.2549
	5m x 5m	4.773ab	0.3288	4.773±0.3288
	6m x 6m	5.322b	0.3439	5.322±0.3439
	p value			0.007
	L.S.D			0.943
Kibwezi	3m x 3m	2.913a	0.2922	2.913±0.2922
	4m x 4m (Normal pruning)	3.631a	0.4229	3.631±0.4229
	5m x 5m	3.848a	0.4864	3.848±0.4864
	6m x 6m	4.327a	0.4806	4.327±0.4806
	p value			0.158
	L.S.D			1.248

Discussion

At 8 years, Melia is half way through its expected rotation age of about 12 to 15 years and the results can be used to indicate the appropriate spacing and pruning treatments for the species. The results showed that the spacing of 6 m x 6 m in Mutomo and Kibwezi superseded the other treatments in terms of height and dbh and crown diameter which could be attributed to less competition for above- and below- ground resources. The comparative tree densities are 1111 for 3 m x 3 m spacing and 278 stems per hectare for the 6 m x 6 m spacing. It is therefore plausible that competition affected height growth in the closer spacing. The results are in agreement with those reported by Sibomana *et al*., 1997 who observed a significant increase in total height for teak with increase in planting spacing at age of 9 years. The study reveals that site factors probably soils, temperatures and rainfall also affected the growth of this species as shown in the results of both sites (Mutomo and Kibwezi).

Recommendations

The authors recommend that assessment of these trials continue for the next 2 years to to monitor any changes in growth, Futures studies will quantify the volume of timber for all the treatments as part of the efforts to prescribe appropriate silvicultural treatment for Melia.

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THEME 2: BIODIVERSITY AND ENVIRONMENT MANAGEMENT (BEM)

Melia volkensii **Candidate Plus Tree**

A natural forest

Benchmarking Edaphic Properties at Arabuko sokoke Forest for Long-term Biodiversity Monitoring

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Abstract

Biodiversity monitoring is an essential aspect of effective forest resource conservation and sustainable management. Monitoring edaphic properties of a forest is a useful tool in forest biodiversity assessment due to the role played by different soil properties in forest regeneration. Spatial and temporal monitoring of soil functions and dynamics provides vital information on response of forest soil to changes in climate, pollution and forest management practices. In light of this, a study was initiated at Arabuko Sokoke forest to monitor changes in biodiversity indicators over a period of time. The experiment was set as a completely randomized design with three treatments (*Brachystegia spiciformis* zone, *Cynometra webberi* zone and mixed forest zone). A total of 27 permanent sample plots measuring 50 m x 30 m each were established. Baseline soil samples were collected for soil physical and chemical analysis using standard procedures. Baseline results indicate that Soil Organic Matter, Total Nitrogen and Carbon were significantly different across the different vegetation zones ($p<0.05$). The Brachystegia and Cynometra zones recorded higher P concentrations of 3.4 ppm and 3.35 ppm, respectively, while the mixed forest zone which is dominated by white sand had a P concentration of 2.7 ppm. The pH was significantly different across the vegetation zones ($p<0.01$). Bulk density of the forest soil was 1.34 g/cm^3 dominated by sandy and sandy loam soils. The baseline soil data is crucial for providing information necessary for developing rehabilitation frameworks and supporting biodiversity related decision making in forest policy and management.

Keywords: Monitoring, Edaphic, Nutrients concentration, Soil fertility, Vegetation zones

Introduction

Understanding the importance of forest biodiversity conservation in the light of climate change is critical at local, national and global levels. One of the prerequisites for sound integration of biodiversity conservation in forest management planning is monitoring its spatial and temporal changes (Gao *et al*., 2014). Enlightened decision making and forest policy and management require reliable information on the status and condition of each forest (Marchetti, 2004). Forest biodiversity assessments are therefore essential if forest resources are to be effectively conserved and sustainably managed.

The main aim of biodiversity monitoring is to address changes over time, thus methods of assessment need to be repeatable and capable of providing comparable results between sampling events. Biodiversity assessments should integrate inventories of several variables to provide information required for future forest assessments (Rica *et al*., 2011). In recent years, there has been an increasing effort to establish temporary and permanent sample plots explicitly for the purposes of biodiversity assessments in forests (Gao *et al*., 2014). Spatial and temporal monitoring of soil functions and dynamics provides vital information on response of forest soil to changes in climate, pollution and forest management practices.

Soils are the basis for all terrestrial life; and the soil on which a forest grows is a critical determinant of forest type and vegetation (USDA, 2016). Soils have provided the foundation for trees and entire forests over millions of years. Soil is an important component of forest and woodland ecosystems as it helps regulate important ecosystem processes, such as nutrient uptake, decomposition, and water availability. Soils provide trees with anchorage, water and nutrients. In turn, trees as well as other plants and vegetation, are an important factor in the creation of new soil as leaves and other vegetation rot and decompose (Faleyimu and Akiyemi, 2010). Soil dynamic changes can also be used as an indicator of a healthy forest ecosystem. In light of this, a baseline study was initiated at Arabuko Sokoke forest (ASF) to monitor biodiversity changes over a period of time (Gao *et al*., 2014). As climate change unfolds, it is likely to alter soil nutrient balance over time due to increased temperatures which enhance nutrient cycling and release, thereby affecting forest regeneration and rehabilitation efforts (Raison and Khanna, 2011).

Materials and Methods

Study area

Arabuko-Sokoke Forest is the largest single block of indigenous coastal forest remaining in East Africa. It is situated in Kenya’s former Coast Province and traverses Kilifi County at a latitude of 3° 20’ S and longitude 39° 50’ E (Figure 1) . The eastern part of the forest lies on a flat coastal plain at an altitude of about 45 m above sea level (a.s.l). This rises to a plateau of about 60 to200 m a.s.l in the central and western parts of the forest. The total forest area is approximately 41,600 ha (ASFMT, 2002). There are three major vegetation types in Arabuko-Sokoke Forest, namely; mixed forest zone, *Brachystegia spiciformis* zone and *Cynometra webberi* zone. The forest has rich biodiversity, including a concentration of endemic and endangered flora and fauna. It has been ranked as the second most important forest for conservation of threatened bird species in mainland Africa. More than 230 bird species have been recorded, including six globally threatened species, namely; Clarke's Weaver (endemic to the forest and its immediate surroundings), Sokoke Scops Owl, Amani Sunbird and Sokoke Pipit (all of which are near-endemics), Spotted Ground Thrush (a rare migrant) and East Coast Akalat (a rare species confined to East African coastal forests).

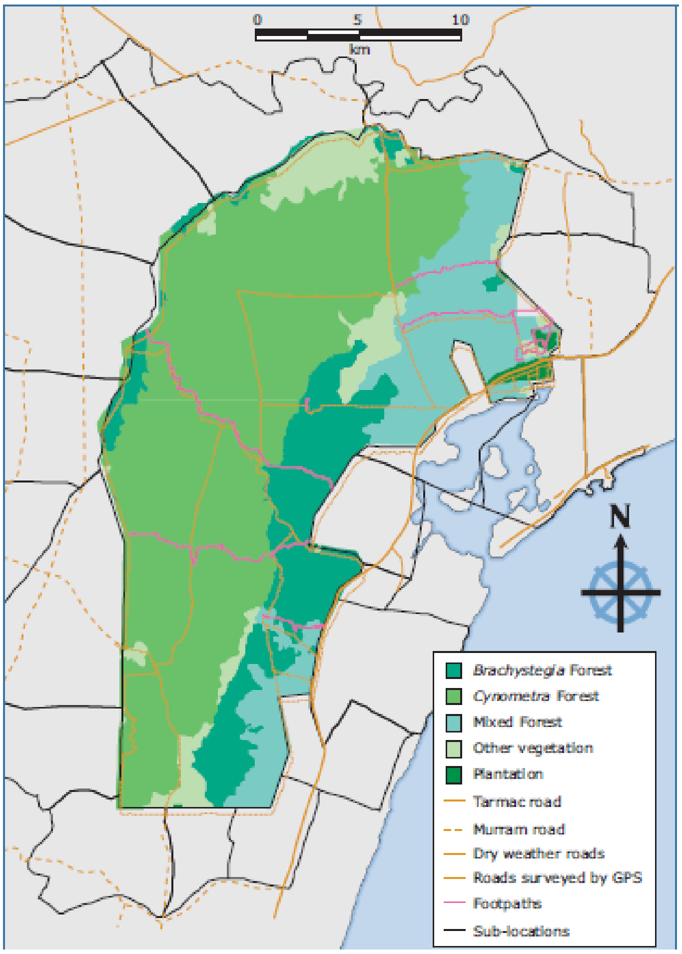

Figure 1. Map of Arabuko Sokoke Forest showing vegetation zones

Experimental design

The experiment was set out as a completely randomized design with three treatments. The forest was stratified into three distinct zones, namely; mixed forest zone, *Brachystegia spiciformis* zone, and *Cynometra webberi* zone which were treated as treatments (ASFMT, 2002). A total of 27 permanent sample plots measuring 50 m by 30 m each were established across the different vegetation zones. Several biodiversity indicators were assessed including edaphic properties of the forest; this was informed by the role played by soil factors in forest regeneration, carbon sequestration and as a habitat for numerous microorganisms. Monitoring of soil changes will be done in five-year intervals.

Forest litter sampling

Forest litter sampling was done to determine thickness of the forest floor. A ring of 30 cm diameter was used to determine amount of leaf litter per unit area. In each plot, the ring was randomly tossed three times and litter captured inside the ring collected for weight determination (Domingo-Quero and Alonso-Zarazaga, 2018).

Soil sampling

In each vegetation zone, two soil profile pits were dug to establish the existing soil horizons (at the beginning and end of each zone). A soil profile pit of 1 m by 1 m by 1 m was dug and soil horizons identified and data recorded. Core samples were then obtained from each soil horizon for bulk density and soil texture determination. Surface soil samples were also obtained using a soil auger across the three vegetation zones for chemical analysis. Grid soil sampling frame was used (Domingo-Quero and Alonso-Zarazaga, 2018). The soil samples were put in zip-lock bags and stored in a cooler box to prevent further changes.

Soil analysis

Soil samples were analyzed for the following components using standard analysis procedures (Okalebo *et al*., 2002). Soil moisture was determined gravimetrically; soil texture was determined using improved hydrometer method for soil particle size analyses; pH and Electro Conductivity values were determined with glass electrode; total nitrogen was determined using kjeldahl method; available phosphorus was analyzed using UV spectrophotometer method; Potassium, Calcium and Magnesium were determined using Atomic Absorption Spectrophotometer.

Data analysis

Analysis of Variance (ANOVA) was conducted using GenStat (Version 16.0 for windows) at 95% confidence level. Means were separated using the Least Significant Difference (LSD) test. Other statistical tests (mean and standard error) were conducted using Microsoft excel.

Results and Discussion

Leaf litter

Forest litter in Arabuko Sokoke forest was found to be significantly different in the various vegetation zones (P<0.01). See Table 1. This could be attributed to the seasonality of leaf fall by different tree species found in the different vegetation zones. Table 1 shows the amount of litter per hectare across the vegetation zones. The *Brachystegia spiciformis* zone recorded the highest amount of leaf litter in the forest. This could be attributed to the deciduous nature of the species which led to massive litter fall during the sampling period due to the dry season (Orwa *et al*., 2009). Mixed forest and *Cynometra webberi* zones recorded leaf litter of 8.59 tonnes per hectare and 7.53 tonnes per hectare, respectively.

Table 1. Forest leaf litter in various vegetation zones at Arabuko Sokoke Forest

Vegetation Zone	Litter Weight (Tons/Ha)
Mixed	8.59 ± 0.82^{b}
Brachystegia	11.68 ± 1.17^{a}
Cynometra	7.53 ± 0.40^{b}
P	<0.01**
LSD	0.089

Note: *Means denoted by the same letter along the same column are not significantly different*

A common feature of the forest floor is the presence of a litter layer composed of dead leaves, twigs and other fragmented organic materials covering the soil. The litter layers play an important role in preventing soil erosion by absorbing the impact energy of raindrops and keeping the infiltration rate high. Soil litter layer also helps limit soil moisture loss from evaporation and reduces amplitudes of soil temperature by insulating the surface (Rawat *et al*., 2009).

The feedback between plant litter fall and nutrient cycling processes plays a major role in the regulation of nutrient availability and net primary production in terrestrial ecosystems. Nitrogen released through decomposition of organic matter is critical for plant productivity and regeneration in many forested ecosystems. Low N availability may be a particularly important constraint in forests where decomposition and mineralization rates are slow. Leaf litter fall constitutes the major part of the total litter fall providing an important nutrient pool (Rica *et al*., 2010). Climate change is however likely to alter decomposition rates through direct effects on soil biotic activity and indirect effects on litter quality with possible impacts on the global Carbon budget and nutrient cycling.

Soil physical characteristics (bulk density and texture)

The soils of Arabuko Sokoke forest had a mean Bulk Density (BD) of 1.34 g/cm^3. There was very little variation in BD along the soil profile. Soil bulk density affects the soil structure in terms of porosity, infiltration, regulation of temperature and governing of plant rooting systems (TARAhaat, 2007). Soils with a bulk density higher than 1.6 g/cm^3 tend to restrict root growth. Bulk density increases with compaction and tend to increase with depth. Sandy soils are also more prone to high bulk density than other soil types (USDA, 2016).

Bulk density is an indicator of soil compaction and soil health. It affects infiltration, rooting depth, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activity, which influence key soil processes and productivity (USDA, 2016). In forested mineral soils, bulk density rapidly increased with depth in the surface but remained uniform at depths >20 cm. This is attributed to distribution of organic matter and compaction. Generally, loose, well aggregated, porous soils and those rich in organic matter have lower bulk density (TARAhaat, 2007; USDA, 2016).

The soils of Arabuko Sokoke were sandy in the mixed forest and *Brachystegia spiciformis* zones; with sandy loam in the *Cynometra webberi* zone (ASFMT, 2002). Sandy loam soils are dominated by sand particles, but contain enough clay and sediment to provide some structure and fertility. Sandy loam soils are capable of quickly draining excess water but cannot hold significant amounts of water or nutrients for plants (Thompson, 2015). This can explain the low available soil moisture and nutrients during the sampling period. Sandy soils are characterized by a low soil organic Carbon, a low cation exchange capacity, a high risk of nutrient leaching, a low structural stability, and a high sensitivity to erosion and crusting. Some tree species requiring low water and nutrients can grow in sandy soils though growth is often stunted (Bell and Sheng, 2006).

Soil organic matter

Soil organic matter (SOM) content at Arabuko Sokoke forest was significantly different across the vegetation zones ($P<0.05$). Soil organic matter was highest in the *Cynometra webberi* zone (1.89 %); with *Brachystegia spiciformis* zone at (1.25 %) and mixed forest zone (1.15 %), respectively. See Table 2. Soil organic matter comprises an accumulation of partially disintegrated and decomposed plant and animal residues and other organic compounds synthesized by the soil microbes as the decay occurs (SERA, 1995).

Table 2. Soil organic matter in various vegetation zones of Arabuko Sokoke

Vegetation zone	SOM %
Mixed Forest	1.1 ± 0.20[b]
Brachystegia	1.3 ±0.21[b]
Cynometra	1.9 ± 0.22[a]
	$F_{2,26}$=3.36 P<0.05 LSD= 0.019

Note: *means denoted by the same letter along the column are not significantly different*

According to Horneck *et al*. (2011), the amount of organic matter in surface, mineral soils can vary from less than 1 % in coarse-textured, sandy soils to more than 5 % in fertile soils. Most SOM is found in the zone of maximum biological activity, the topsoil or plough layer. Soil organic matter is a surrogate for soil Carbon and is measured as a reflection of overall soil health. When monitored for several years, it gives an indication whether soil quality is improving or degrading (SERA, 1995).

Soil organic matter is important to a wide variety of soil chemical, physical, and biological properties. As SOM increases, so does Cation Exchange Capacity (CEC), soil total N content, and other soil properties such as water-holding capacity and microbiological activity (Horneck *et al*., 2011; University of Connecticut, 2015). Climate change, however, is likely to alter decomposition rates through direct effects on soil biotic activity and indirect effects on litter quality with possible impacts on the global Carbon budget and nutrient cycling. Tropical forests like ASF are likely to be more affected by changes in soil water availability (caused by the combined effects of changes in temperature and rainfall). Decreases in soil moisture may accelerate forest loss in many areas where water availability is already marginal (Miko and Fischlin, 2015).

Soil pH and electrical conductivity (EC)

The soil pH at ASF ranged from moderately acidic to slightly acidic, i.e. 6.7, 6.2 and 5.8 for mixed forest, *Brachystegia spiciformis* zone and *Cynometra webberi* zone, respectively. See Table 3. The pH was significantly different across the various vegetation zones (P<0.01, LSD= 0.00099). This can be attributed to the difference in soil types in the three vegetation zones of Arabuko Sokoke Forest. Soil pH affects the availability of necessary plant nutrients with mineral release inhibited by the acidic nature of many tropical soils.

Table 3. Soil pH at Arabuko Sokoke Forest

Vegetation Zone	pH
Mixed	6.67± 0.10[a]
Brachystegia	6.24±0.11[b]
Cynometra	5.79± 0.12[c]
	$F_{2,26}$= 16.12
	p<0.01***
	LSD=0.00009

Note: *Means denoted by the same letter along the same column are not significantly different*

The average soil EC at Arabuko Sokoke forest was 0.035 for mixed forest zone, 0.024 for *Brachystegia spiciformis* zone and 0.029 for the *Cynometra webberi* zone. The low EC is an indication of low concentration of soluble salts in the soil (Apal, 2015). High soil salinity has been identified as one of the main factors that limit the spread of plants in their natural habitats. The problem is escalated in arid and semi-arid regions where evaporation is high (Amira, 2011). Electrical Conductivity (EC) testing is a reliable way to assess how salts are affecting plant growth thus providing a guide for species selection in developing reforestation frameworks. Generally, an EC (1:5) of less than 0.15 will not affect plant growth (Apal, 2015).

Soil nutrients

Total Nitrogen and Carbon

Total Nitrogen was significantly different across the various vegetation zones ($F_{2, 26}$=3.57, $p<0.05$, LSD= 0.026). The baseline results indicated low soil nitrogen content ranging from 0.06 % in mixed forest and *Brachystegia spiciformis* zones, and 0.09 % in the *Cynometra webberi* zone (Figure 2). This could be attributed to low mineralization as a result of low soil moisture which may have hindered microbial activities. The coarse textured soil could have also contributed to leaching of nitrates due to their low adsorption capacity (Burgos *et al*., 2006). This is as a result of the low water holding capacity of sandy and sandy loam soils.

Soil Carbon was also significantly different across the vegetation zones ($F_{2, 26}$=3.47, $p<0.05$). Generally, soil Carbon was at 0.66 %, 0.73 % and 1.11 % for mixed forest, *Brachystegia spiciformis* and *Cynometra webberi* zones, respectively. The amounts of Carbon stored in soils and vegetation and the potential of forestry to influence Carbon release is of paramount importance. Soil Carbon content is strongly related to climate and altitude. Forest felling may result in decreases in soil Carbon store, due to soil disturbance and changes in microclimatic conditions. Shortening forest rotations may result in long-term declines in soil Carbon storage (Harrison *et al*., 1995).

Soil organic Carbon stored in forest soils comprises about 73 % of global soil Carbon storage and is an important component in forest soils and ecosystems. Its accumulation and decomposition rates have direct effects on terrestrial ecosystem carbon storage and the global Carbon balance. Thus, understanding SOC distribution in forest ecosystems is critical. This variability in belowground C is an important consideration for evaluating forest management options that maintain and promote soil organic Carbon storage instead of loss as Carbon dioxide to the atmosphere (D'Amore and Kane, 2016).

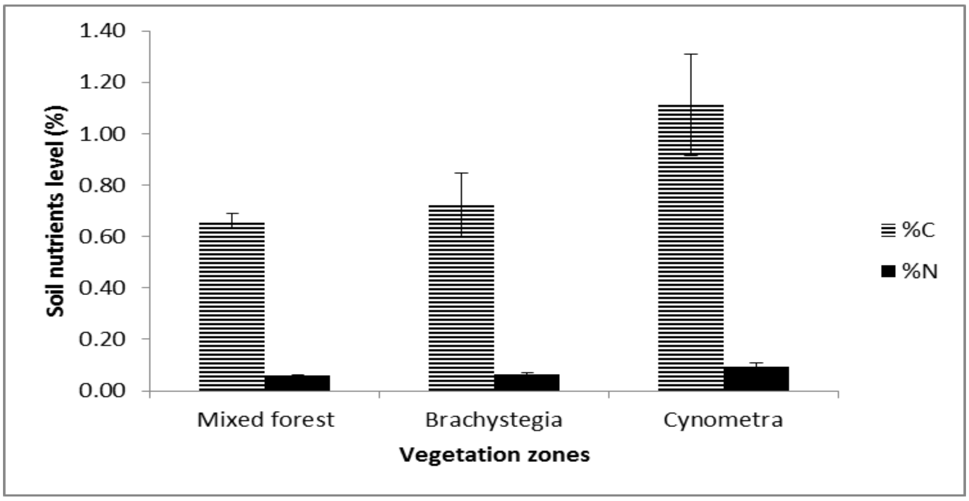

Figure 2. Soil Nitrogen and Carbon concentration at Arabuko Sokoke Forest

Phosphorus

Figure 3 shows the concentration of available phosphorus (P) across the different vegetation zones at Arabuko Sokoke forest. The concentrations were low across the vegetation zones, recording 2.7 ppm, 3.4 ppm and 3.35 ppm for Mixed forest zone, *Brachystegia spiciformis* and *Cynometra webberi* zones, respectively. This could be attributed to slow P mineralization during the sampling period as a result of dry weather. Climatic and site conditions, such as rainfall, temperature, moisture and soil aeration, and salinity affect the rate of P mineralization. Organic matter decomposes releasing P more quickly in warm humid climates. Phosphorus is released faster when soil is well aerated (USDA, 2016).

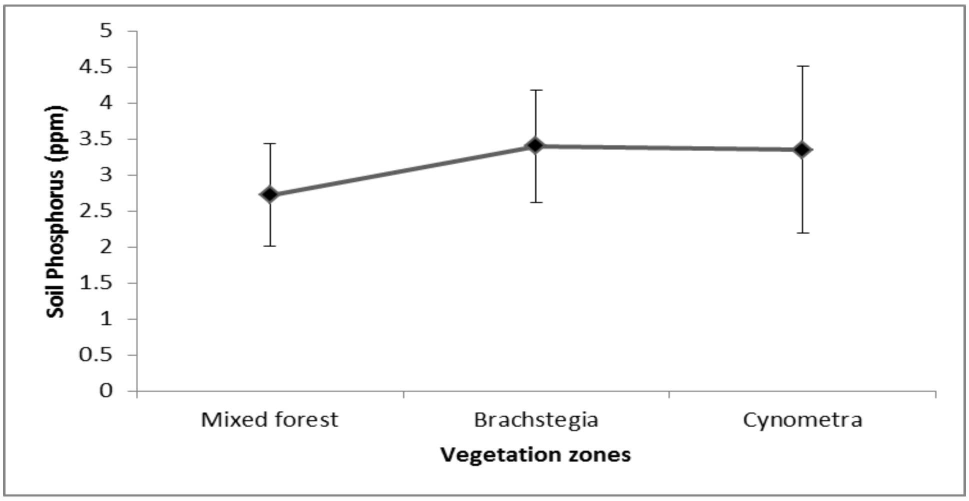

Figure 3. Concentration of phosphorus in Arabuko Sokoke Forest

Phosphorus is most available at a pH of 6.5 and in moist, warm conditions. In addition to losses through surface runoff, leaching has lately gained increased attention as an important P transport pathway (Djodjic *et al*., 2004). The low P concentration in forest soils dominated by porous dry sand may be attributed to this phenomenon. Although phosphate P is strongly adsorbed in many soils, it is quickly transported through the soil by preferential flow. Earlier studies revealed that P was very immobile in the top soil. The higher P fixing capacity of the top soil appeared to restrict the P mobility (Sinaj *et al*., 2002).

Soil Exchangeable Bases

Soils at the ASF had moderate Calcium concentrations of 694 ppm, 220 ppm and 111 ppm for mixed forest, *Brachystegia spiciformis* and *Cynometra webberi* zones, respectively. Calcium deficiencies are usually found only on very acidic soils. This explains the low level of Calcium in the *Cynometra webberi* zone which had a pH of 5.8. Concentration of Magnesium in Arabuko Sokoke forest was high at 217 ppm, 165 ppm and 208 ppm for mixed forest, Brachystegia and Cynometra zones, respectively. The concentration of Potassium was low across the various vegetation zones with mixed forest, Brachystegia zone and Cynometra zone recording 49 ppm, 38 ppm and 53 ppm, respectively.

The exchangeable Ca and Mg pools are two of the most important nutrients in forest soils. The large quantities of Ca and Mg retained on the cation exchange sites resupply the soil solution consequently playing an important role in the cycling and retention of other nutrients. The exchangeable concentrations of base cations largely govern soil acidity, and Ca and Mg are the two most abundant base cations in the forest soils (Kabrick *et al*., 2010).

Conclusion

The baseline data shows that soil at Arabuko Sokoke forest provide optimal nutrients to sustain forest regeneration. The bulk density of 1.34 g/cm^3 is also favorable for root penetration, enhanced infiltration and enhanced water holding capacity. Continuous monitoring of the edaphic properties of the forest should be done to assess forest health over a period of time. The baseline soil data is crucial for providing information necessary for developing rehabilitation frameworks and supporting biodiversity related decision making in forest policy and management.

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Water Quality Status in Mt. Elgon and Cherangany Forested Ecosystems

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Abstract

Mt Elgon and Cherangany hills forest ecosystems are threatened by increase in local population causing environmental degradation and disruption in the catchment area resulting in drying up of streams and rivers and both water and soil pollution. The objective of this study was to conduct a baseline survey to provide information on the status of water quality in the catchment and an overview of pollution levels, sources and possible mitigation measures. Water and sediments from 26 spatial distributed sites on rivers in catchment were sampled and analyzed. The water quality (physical and chemical) was assessed through analysis of water and sediments. Both water and sediments were analyzed following the analytical standard methods. All the rivers in the catchment contained high levels of iron and turbidity which exceeded environmental limits in Kenya. There was no pollution of water from heavy metals. River Nzoia near Webuye town and Sigomre bridge were the most polluted waters. For sediments; copper, magnesium and iron were high in the upper catchment. Nitrates and phosphates in sediments were high in the lower catchment. The recommended interventions to manage point or non-point pollution sources include: land and soil conservation to reduce erosion, precision in fertilizer usage, proper sewage and industrial effluent treatment and disposal. The mitigation measures should be at the sub-catchment level to reduce land, soil and water pollution. Technologies for soil and water conservation including afforestation on bare lands, control of overland flow, reduction on river bank cultivation and conservation agriculture practices will reduce pollution and conserve the environment.

Keywords: Catchment, Ecosystem, Environment, Quality, Sediments, Soil, Water, Watershed

Introduction

Mt Elgon and Cherangany hills forest ecosystems are part of the Kenya's water towers and are the major sources of rivers draining into Lakes Victoria and Turkana (KFS 2016; Rhino Ark, 2014). These ecosystems also recharge ground-water aquifers, reduce soil erosion into rivers and regulate local climatic conditions as well acting as carbon reservoirs and sinks (Rhino Ark, 2014). The two forested ecosystems are threatened by human population pressure causing land, soil and water degradation in the catchment area (KFS 2016; Adoyo and Wangai, 2012). The degradation of land, soil and water lead to drying up of rivers, pollution and reduction in water bodies' levels in the catchment. Deforestation of these water towers as a result of human settlement and agriculture has increased surface runoff leading to soil erosion. The eroded soils cause siltation of water bodies reducing discharge volumes and causing floods. For instance, flooding is a perennial problem in the lower River Nzoia which sometimes causes loss of lives and property destruction (Shilenje and Ogwang, 2015). Water pollution in the catchment is from both point and non-point sources which are mostly anthropogenic (Hecky *et al.*, 2000; Twesigye *et al.*, 2011). High levels of phosphates, nitrates and banned compounds such as aldrin, dieldrin and DDT in water have been reported in River Nzoia Basin which has been attributed mainly to agricultural activities (Twesigye *et al.*, 2011). Furthermore, nutrients mostly nitrates, phosphates, total organic carbon among others from surface runoff are a major cause for eutrophication in Lake Victoria resulting in massive algae blooms, water hyacinth infestation and oxygen depletion in water (Hecky *et al.*, 2000; LVEMP, 2004; Wogenga'h *et al.*, 2004).

Water quality assessment evaluates the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses (WHO, 1991); GESAMP (1988).
In Kenya, the Environmental Management and Coordination, (Water Quality) Regulations 2006 of the Environmental act of 1999, outlines the permitted levels of water quality parameters for different uses (Kenya Gazette, 2006). Changes in the physical and chemical parameters of water affect water quality and they mainly include: pH, dissolved oxygen, biological oxygen demand (BOD), chemical oxygen demand (COD), turbidity, phosphates, nitrates, electrical conductivity, and heavy metals among others. The pH of river water is vital to aquatic life and affects the ability of aquatic organisms to regulate basic life-sustaining processes. Alkalinity is a measure of all the substances in water that can resist a change in pH when acid is added to the water (USEPA), (1999). Turbidity is a measure of dissolved coloring compounds in water and can be attributed to presence of organic and inorganic materials. The suspended solids in water are closely linked to erosion and nutrient transport, industrial waste and chemicals used in agriculture. Nitrogen is of great importance

to the quality of water in rivers, and as a nutrient in water may cause eutrophication. Nitrite which is an intermediate in oxidation of ammonia and nitrate is toxic to aquatic life and is commonly found in sewage effluents which are rich in ammonia. The biochemical oxygen demand (BOD) measures biologically oxidized pollutants while chemical oxygen demand (COD) measures the chemically oxidized ones in water. BOD is mostly associated with wastewater from sewage systems while COD associated with industrial effluents. In the River Nzoia basin, the dissolved oxygen and BOD have been found to fluctuate with rainfall patterns which affect the discharge volumes (Kanda *et al.*, 2015). The purpose of this study was to provide information on the water quality status in the catchment area and give an overview of the pollution levels, interventions and the mitigation measures. The water quality was assessed through analysis of water and sediments for physical and chemical parameters.

Materials and Methods

Study area: Mt. Elgon and Cherangany forest ecosystems/River Nzoia Catchment

Mt. Elgon forest ecosystem forms the upper catchment area for three major rivers: Nzoia, Malakisi and Sio which drain into Lake Victoria and transverse through Bungoma, TransNzoia, Kisumu, Siaya and Busia counties. The Cherangany hills forest ecosystem and streams west of the Cherangany hills watershed feed the Nzoia river system. The river Kapolet originating from Kapolet Forest in Elgeyo Marakwet County is a tributary and source of river Nzoia and provides water consumed in Trans Nzoia and Bungoma Counties. The specific spatial distribution of sampling sites on rivers for water quality is as shown in Table 1 and Figure 1

Table 1. Spatial distribution of sampling sites on rivers for water quality

Name of River	GPS coordinates
1. River Chepkaitit near Kapcherop town bridge	E 759718 N 114865
2. River Seum at Mito mbili bridge	E 748821 N 109284
3. River Chepkaitit at chepkaitit bridge	E 749216 N 105057
4. River Kapterit at Mwaita bridge	E 744785 N 113891
5. River Nzoia at Kapolet North water treatment site	E 740840 N 125332
6. River Nzoia at Kapolet bridge	E 739806 N 126279
7. River Koitobos (Koitobos bridge)	E 73048 N 113274
8. River Nzoia at Moiben bridge	E 737301 N 102361
9. River Moiben at Moiben bridge	E 737336 N 101603
10. River Kiptogot near Chepchoina centre	E703463 N 10126765
11. River Mubere at Mubere bridge	E704720 N 10123541
12. River Kaibei/Koitobos	E 704883 N 10122810

Name of River	GPS coordinates
13. River Sabwani at Endebess bridge	E 706436 N 119732
14. River Nzoia at Moi'sbridge Town bridge	E 735602 N 97701
15. River Sosian downstream at Kamagut bridge	E 742637. 20 N 61031.76
16. River Sosian Eldoret downtown bridge	E 754370. 32 N 56014.889
17. River Sergoit/Chepkoilel near Tarbo bridge	
18. River Kipkaren at Kipkaren Town bridge	E 718672.91 N 67095.70
19. River Nzoia at Brigadier bridge in Soysambu	E 729591.44 N 84121.08
20. River Kiminin at Kiminin bridge	E 714458.89 N 85338.48
21. River Nzoia at Webuye bridge	E 701083.88 N 64808.780
22. River Kuywa at Lake Victoria Basin water treatment site	E 689170.71 N 68588.14
23. River Nzoia at Mumias bridge	E 665470.78 N 40837.75
24. River Lusumu at Mumias-Musanda Road Bridge	E 664630.91 N 33860. 39
25. River Nzoia bridge at Sigomre/Sigomere bridge	E 649271.31 N 27541.15
26. River Nzoia at Ruambwa bridge	E 621665.007 N 12979.32

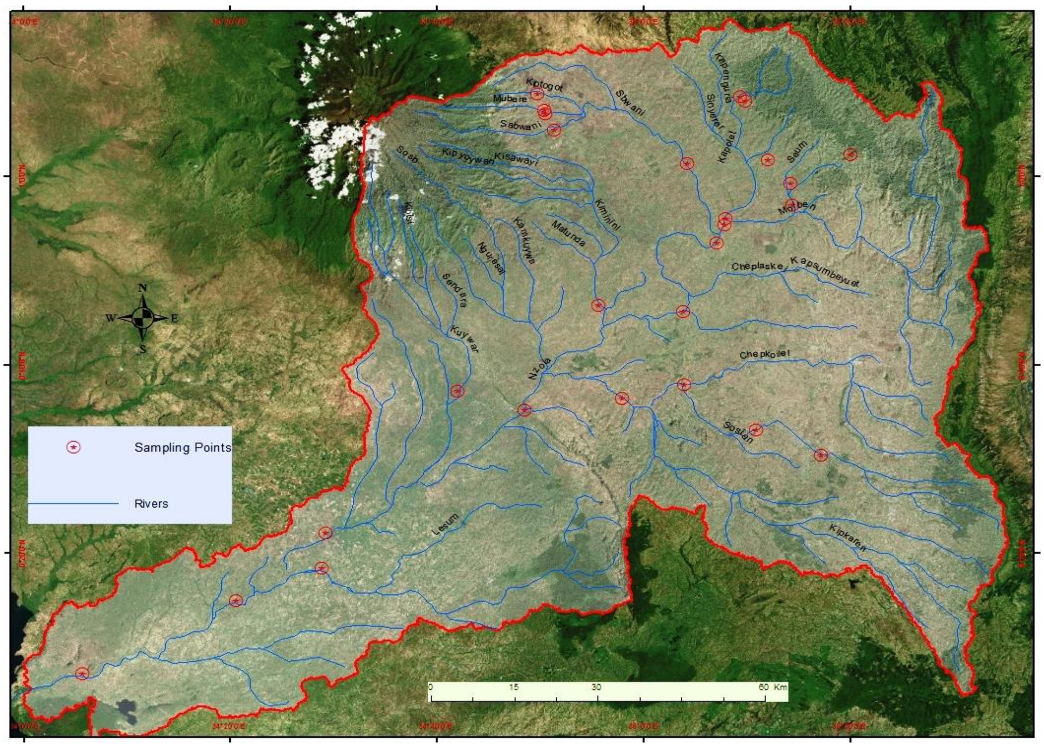

Figure 1. Water and sediment quality sampling sites in the River Nzoia catchment

Assessment of water quality

The water quality was assessed through analysis of water and sediments. The sampling activity was done in August 2017 during the short rains. For water sampling, samples were taken in the surface water layer (0-5 cm from the surface) at the center of the main flow. The sediment samples came from three equidistant positions within a 50 m diameter radius i.e. at the either sides of the river banks. Sediments were taken at exact or near water sample points because the sediment study was linked to a water quality. Both physical (Turbidity, TSS, TDS, pH etc.) and chemical parameters (nitrates, nitrites, phosphates, COD, BOD and heavy metals) of water were analyzed while chemical parameters only for sediments. Both water and sediments were analyzed following the analytical standard methods. The contents of nitrate, nitrite, phosphate, zinc, iron, copper, chromium, hardness, and alkalinity were measured spectrophotometrically. TDS, turbidity, pH, conductivity, and temperature were measured potentiometrcally. TSS was measured by gravimetric method. COD was measured using reactor digestion method while BOD was measured respirometrically. The coliform bacteria were measured by membrane filtration, lead measured using ISO 8288, cadmium (ISO 5961), arsenic (ISO 11969) and mercury measured using USEPA-245 protocols. For sediments; nitrates and phosphates were determined spectrophotometrically. The total organic carbon (TOC) was determined by Loss on Ignition method. Zinc, iron, copper and magnesium were determined using atomic absorption spectrophotometry. The pH and conductivity were measured by potentiometric method. Turbidity, temperature, pH and electrical conductivity were measured onsite in the field during sampling.

Results and Discussion

Nitrates and Nitrites

In this study, river Nzoia at Webuye Bridge recorded the highest nitrate levels of 13.3 mg/L against acceptable limit of 10 mg/L (NEMA, 2006). Similarly, high levels of nitrites of 0.099 mg/L against acceptable limits of 0.1 mg/L (KEBS, 2014) were recorded at the same site. The highest nitrite levels of (0.167mg/L) were recorded at Sosiani river downstream at Kamagut bridge. The nitrate levels of rivers Chepkaitet (Chepkaitet bridge), Koitobos (Koitobos bridge), Sosian at Kamagut bridge and Kipkaren at Kipkaren bridge (6.3, 5.4, 5.1 and 5.1 mg/L) were below the acceptable limits of 10 mg/L but require close monitoring as their levels were relatively high (Figure 1, Figure 2, Figure 3 and Figure 4).

The high levels of nitrates and nitrites were attributed to pollution from the nearby town industries and agricultural activities in the region. The high levels of nitrate in the river Nzoia catchment have been associated with water hyacinth and algae blooms in the Lake Victoria adversely affecting fish and other aquatic animals. According to the United States Environmental Protection Agency (USEPA) (1999), consumption of water by humans containing high levels of nitrate in excess of 10 mg/L could lead to adverse health effects such as methemoglobinemia ("blue baby" syndrome). Nitrate and nitrite levels in both water and sediment had similar trends in selected sites notably Sosiani River whereby the high levels in water correlated with the sediment levels. In addition, the farming activities around the sampled areas could also have contributed to the nitrate levels in sediments. The undetected levels of nitrate in sediments in some sites were largely attributed to high solubility of nitrates in water (Figure 3).

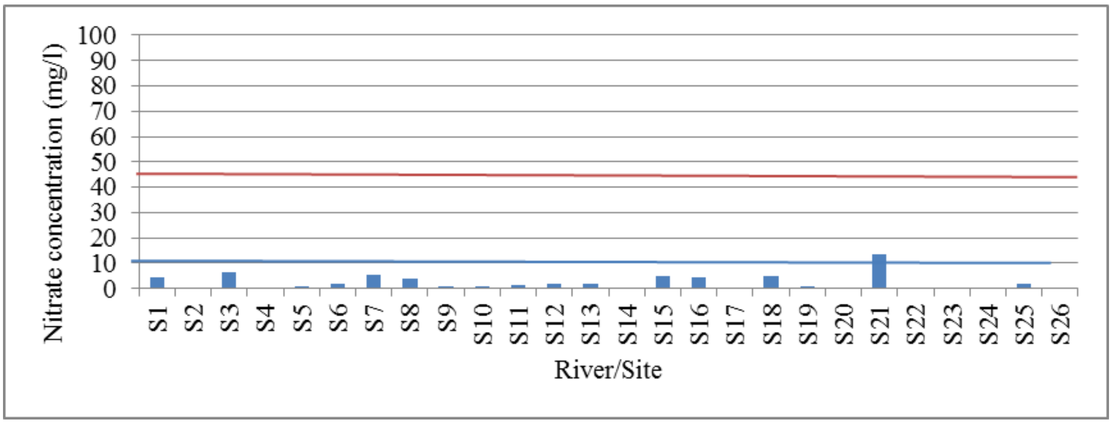

Figure 2. Nitrate levels in water

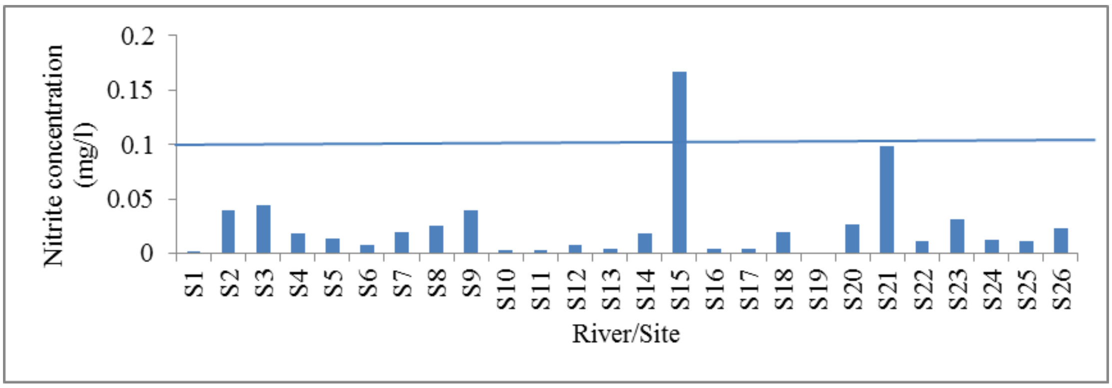

Figure 3. Nitrite levels in water

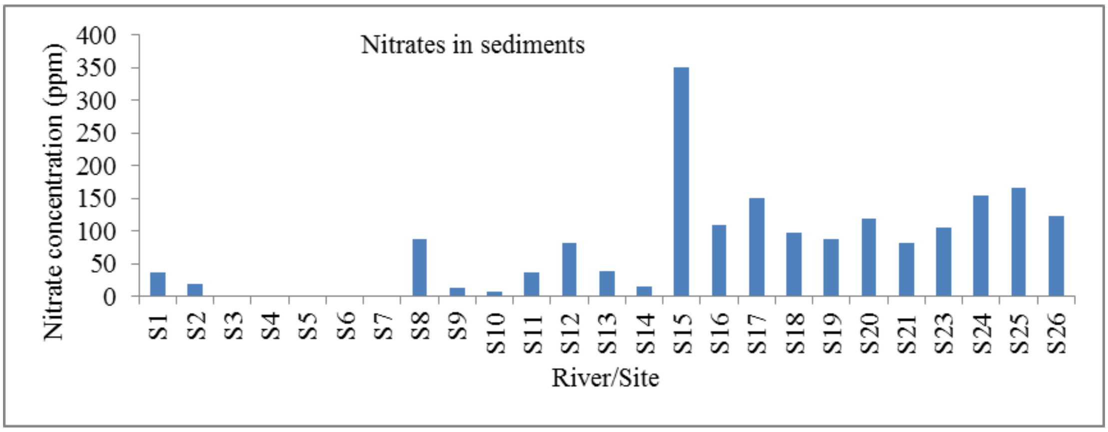

Figure 4. Nitrates in river sediments

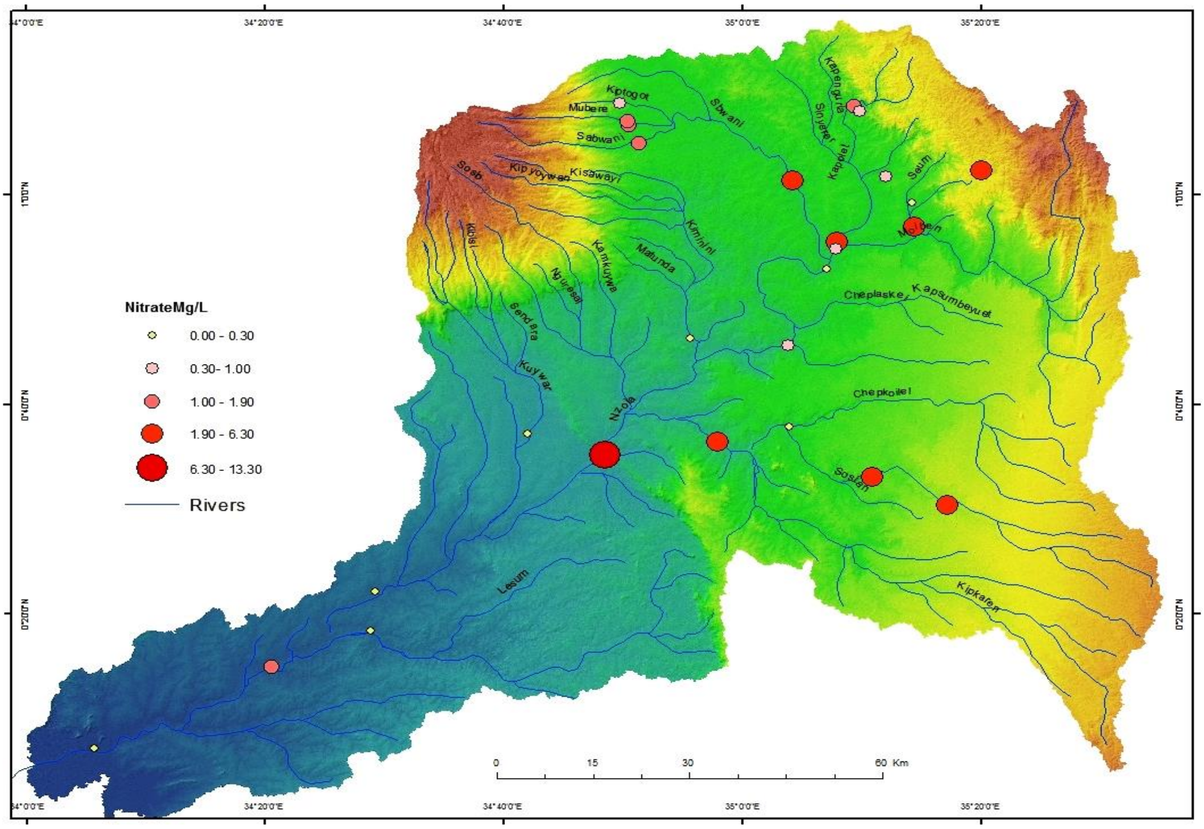

Figure 5. Pollution map for Nitrate levels in water

Phosphorus

Phosphate concentrations recorded from the rivers sampled in Mt Elgon and Cherangany forest ecosystems, were significantly low except for rivers Sabwani, Sosian and Kiminini recording concentrations of 2.56mg/l, 2.49 mg/l and 41.5 mg/l respectively against acceptable limit of 2.2 mg/L (KEBS, 2014) as shown in figure 6. These high phosphate concentrations could mainly be attributed to surface runoffs from farming activities and livestock waste in the surrounding areas. For river Sosiani, the high levels of phosphates were attributed to municipal waste from Eldoret town. With this high levels of phosphates, there is likely to be eutrophication downstream (lower catchment) of river Nzoia resulting to problems like excessive growth of water hyacinth as witnessed at Ruambwa and Sigomre sites along River Nzoia. In addition, this eutrophication also depletes dissolved oxygen levels in water which is detrimental to aquatic life.

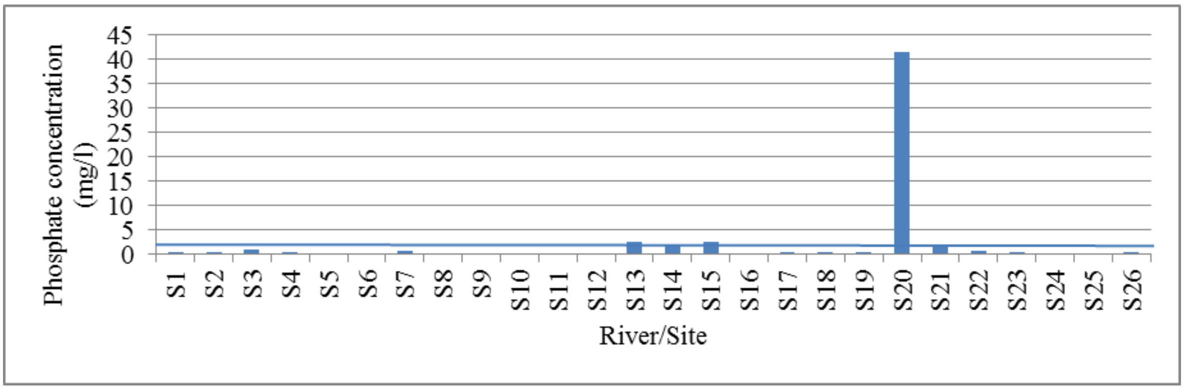

Figure 6. Phosphates levels in water

The amount of phosphorus present in a water body depends on both the external phosphorus load and its release and retention in the sediments. Sediments act as a sink where phosphorus can be stored, and as a source of phosphorus for the overlying river water. In this study, total phosphorus concentrations in sediments varied considerable ranging from 29 ppm to 619 ppm. The lowest concentrations of 29 ppm recorded were at River Nzoia at Kapolet North water treatment site which is the source of River Nzoia in the Cherangany forested hills which was less polluted. High concentrations recorded at rivers Chepkaitet, Seum, Sosian and Nzoia at Webuye town of 544 ppm, 609 ppm, 619 ppm and 583 ppm respectively (Figure 7) could be as a result of erosion from run-offs, non-point sources of pollution such as municipal waste, waste water, sewerage, and farming activities; and point-source pollution from industries around Webuye town.

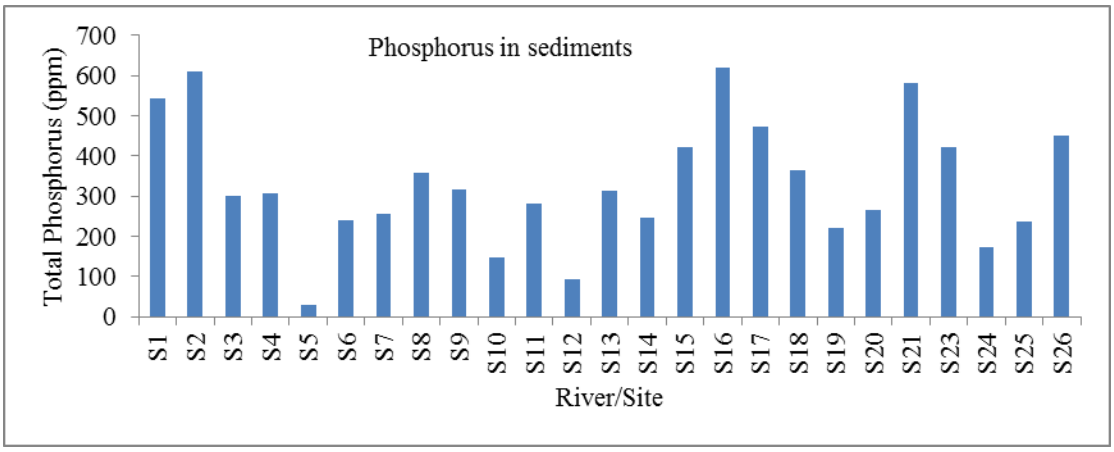

Figure 7. Total phosphorous in sediments

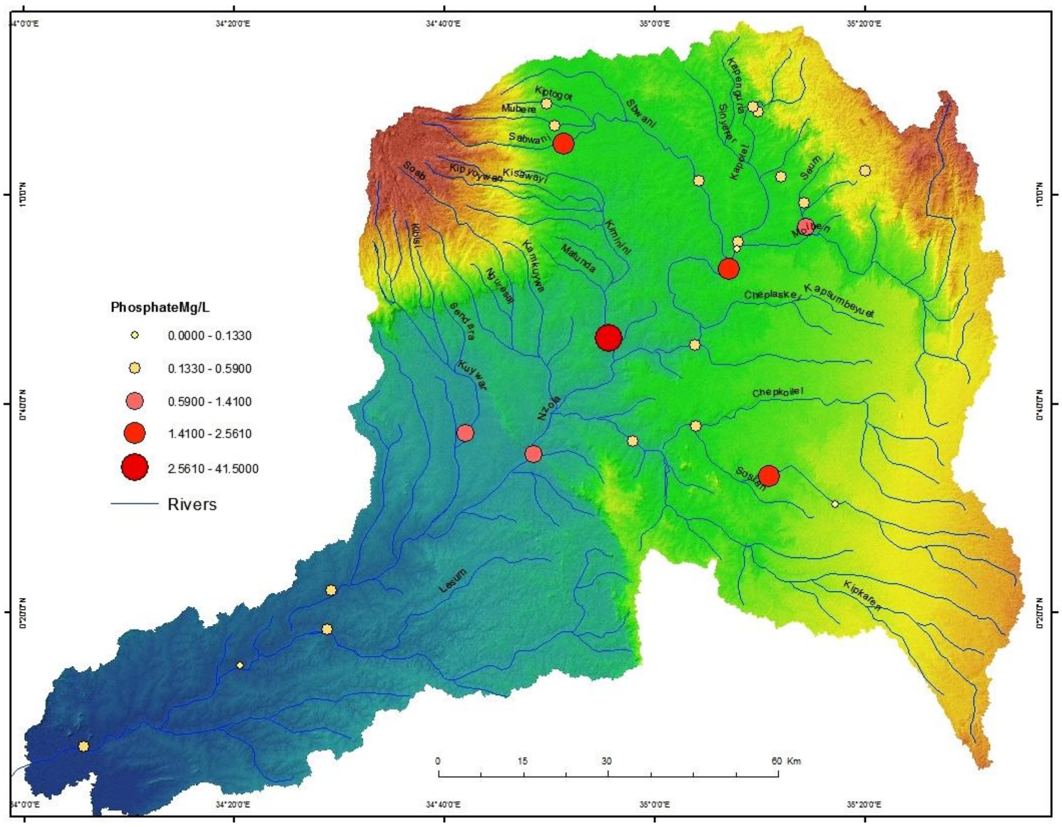

Figure 8. Pollution map for Phosphate levels in water

Alkalinity

All the sampled sub-water catchments had alkalinity values of between 11 mg/L and 52 mg/L except for Kipkaren river in the Chepkoilel sub-catchment watershed which had the highest alkalinity value of 116 mg/L, and this could be attributed to the extensive and intensive farming activities (Figure 9). These concentrations of alkalinity in water protect aquatic life against rapid changes in pH.

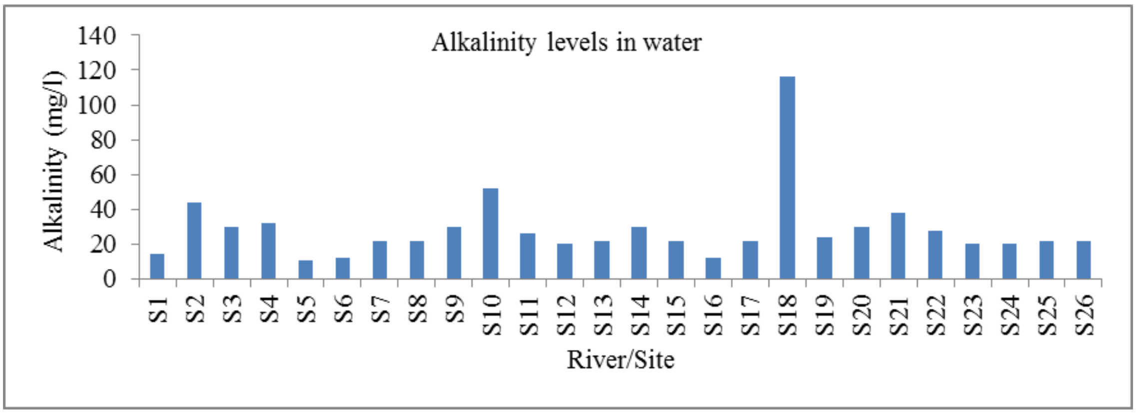

Figure 9. Alkalinity levels in water

pH and Electrical conductivity

The pH values of the sampled rivers were all within acceptable limits (NEMA, 2006; KEBS, 2014). The same trend was observed for sediments except for River Nzoia at Kapolet Bridge which recorded a low pH of 5.75 (Figure 10 Figure 11). The low pH could be attributed to anthropogenic activities mostly pollution from phosphates and nitrate fertilizers as well as animal watering points in the sub-catchment. Most aquatic organisms prefer water with pH range of between 6.5 and 8.4. Water with a pH of less than 4.8 or greater than 9.2 can be harmful to aquatic life.

The electrical conductivity of the river waters were within the acceptable limits (2.5 -11.5 mS/m) against maximum acceptable limit of 250 mS/m (KEBS, 2014) (Figure 12 Figure 13). This implied that there was a low pollution of ionic salts in the rivers from the catchment. For sediments, there was a correlation between the electrical conductivity and metal cations concentration for copper, zinc and magnesium (Figures 26- Figure 31).

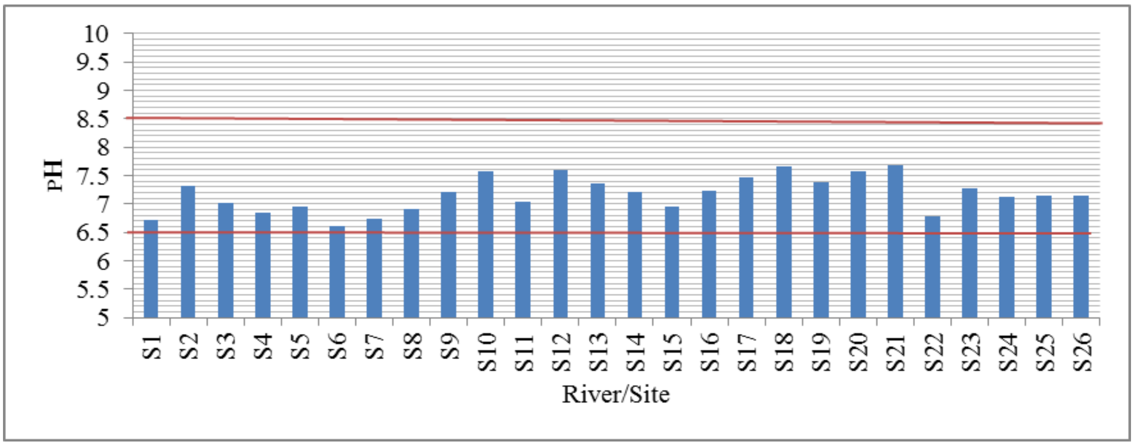

Figure 10. The pH levels in water

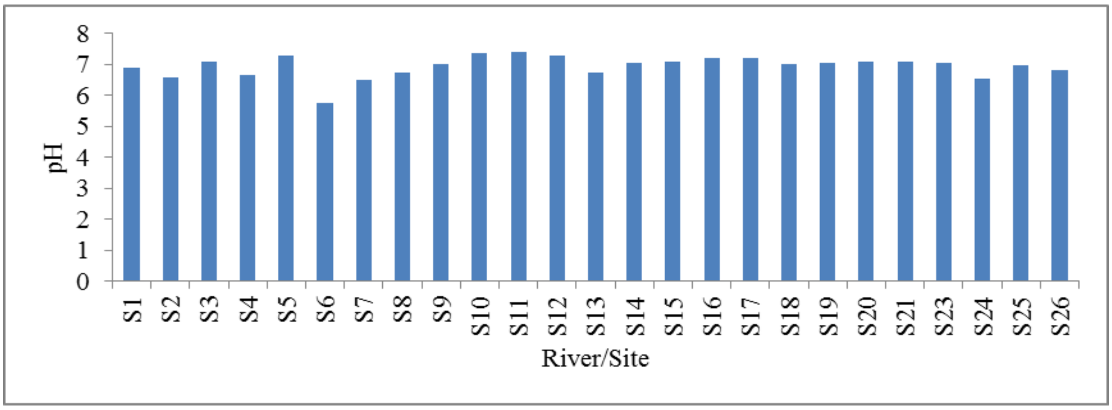

Figure 11. The pH levels for sediments

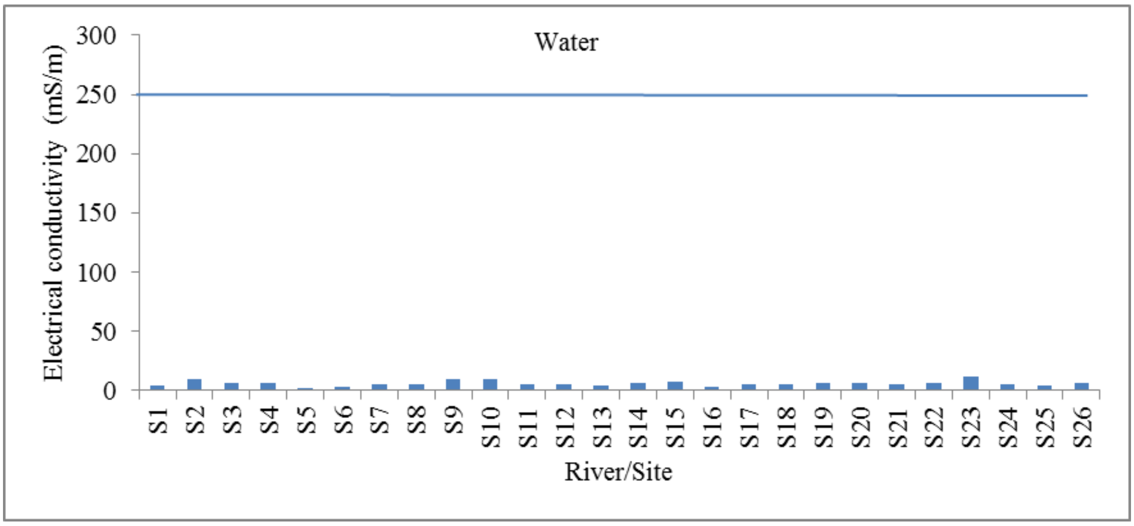

Figure 12. Electrical conductivity of water

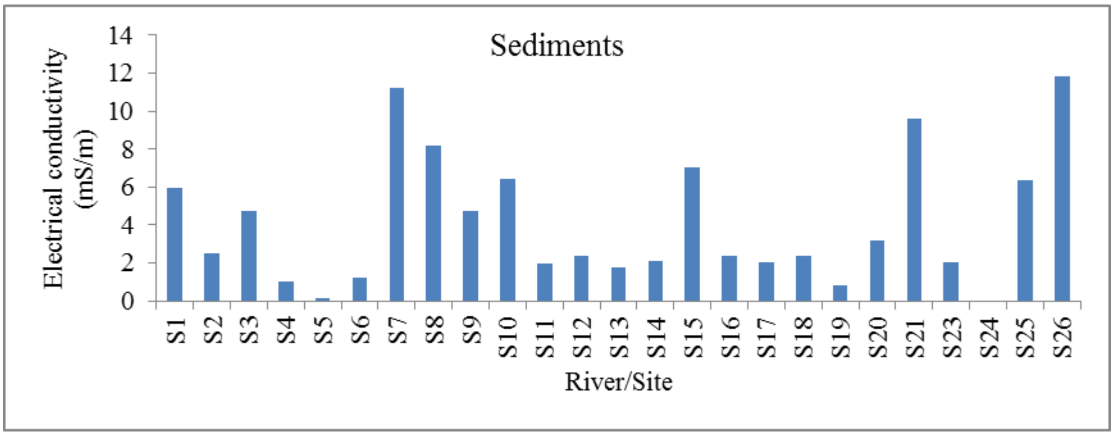

Figure 13. Electrical conductivity for sediments

Total Dissolved Solids (TDS)

In Kenya, the total dissolved solids (TDS) concentrations in drinking water should not exceed 1200 mg/L (KEBS, 2014) while water quality standards for domestic water sources should not exceed 1500 mg/L (NEMA, 2006). All the recorded concentrations of total dissolved solids (33 – 352 mg/L) were below the maximum allowed limits implying that the river water do not have high concentration of dissolved solids (Figure 14)

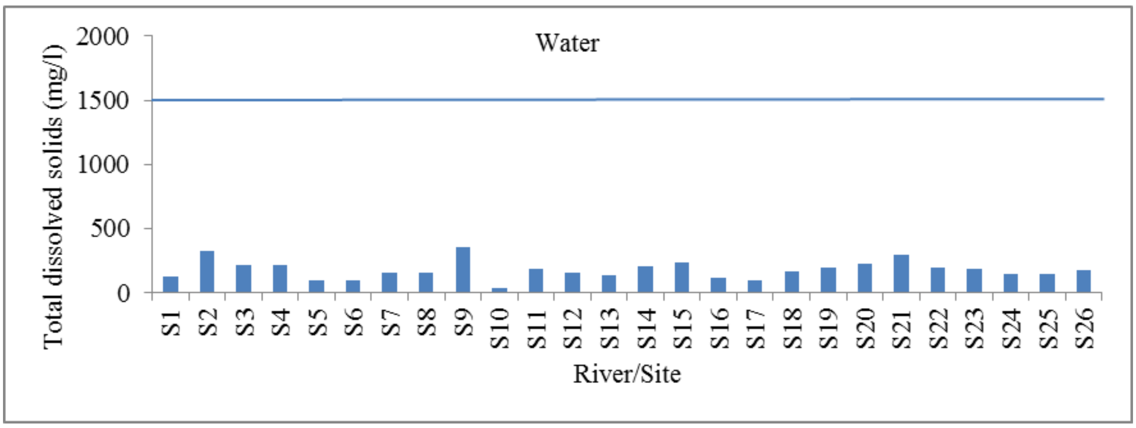

Figure 14. Total Dissolved solids in water

Total Suspended Solids (TSS)

The volume of the suspended solids in water in all the sub-catchments was within the NEMA water quality acceptable limits of 30 mg/l for domestic and commercial water in Kenya (NEMA, 2006). The low levels of TSS in water were attributed to the sampling period whereby, it was done during the rainy season and river discharge rates were high hence the suspended solids were washed away downstream. However, for drinking water, the TSS levels should not be detected as per KEBS portable water standards (KEBS, 2014) as shown in Figure 15.

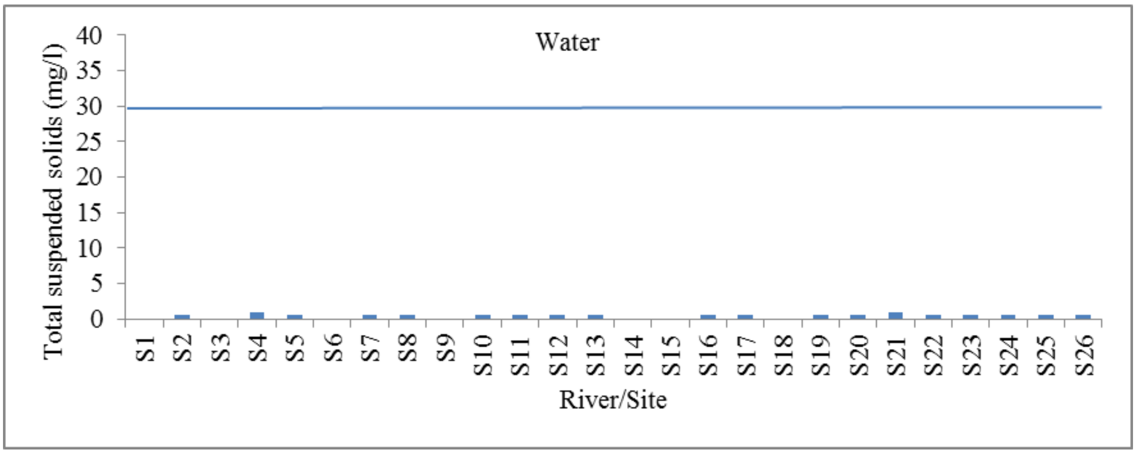

Figure 15. Total Suspended Solids in water

Turbidity

In this study, the turbidity levels of the sampled rivers were high (45-700 NTUs) and beyond acceptable limits set for drinking water in the environment in Kenya (KEBS, 2014) i.e. 25 NTUs and therefore requires timely interventions. These high levels were attributed to seasonal weather variations and land use activities at the time of sampling whereby it was in a rainy season with high rates of soil being eroded into rivers through surface runoff. Furthermore, high turbidity was also synonymous with big rivers perhaps due to high sediment load as a result of high discharge volumes as shown both in the upper and lower catchment areas of river Nzoia near the mouth of Lake Victoria (Figure 16; Figure 17). For instance, River Nzoia at Kapolet Bridge (471 NTUs), River Koitobos at Koitobos Bridge (597 NTUs), and the larger River Nzoia at Moi'sbridge bridge (427 NTUs), Sigomre and Ruambwa bridge (664 NTUs), sites are big rivers which were very turbid (Figure 16). Low clarity levels in water reduce sunlight absorption causing high temperatures which in turn lower oxygen levels. This is detrimental to aquatic life as photosynthesis is also affected due to reduced light penetration.

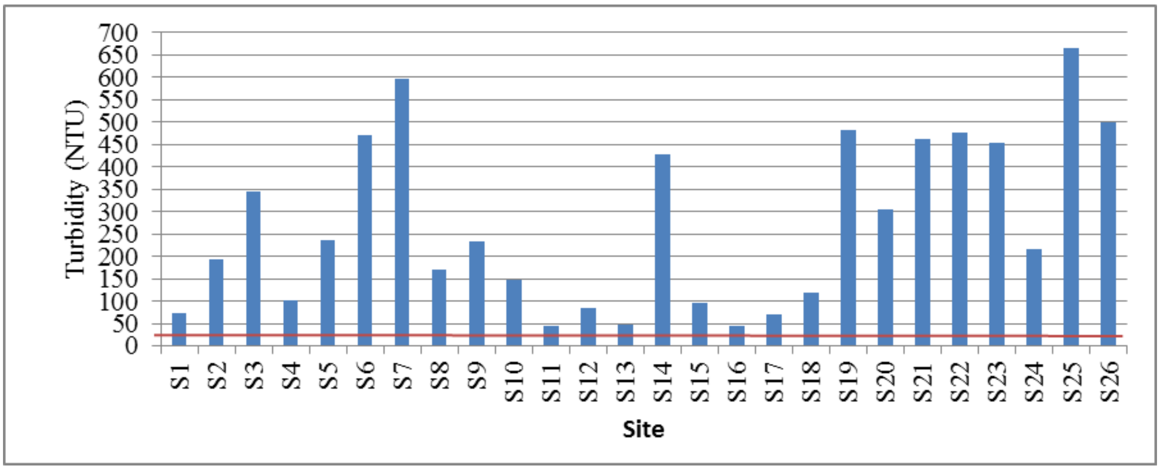

Figure 16. Turbidity levels of water

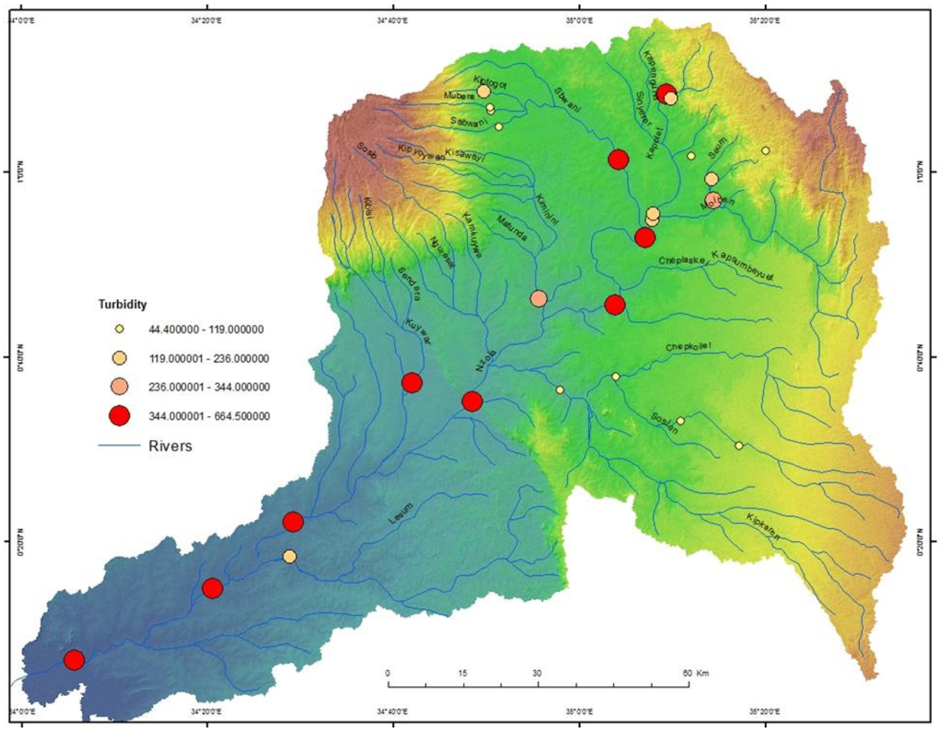

Figure 17. Pollution map for Turbidity levels in water

Water Temperature

Temperatures ranged from 16°C along River Chepkaitit in Kapcherop (2353m absl) to 22.9°C (1180m absl) on River Nzoia at Rwambwa bridge (Figure 18). These water temperatures variations were majorly attributed to altitude and prevailing weather conditions. In addition, other factors known to influence water temperatures include; shading and ground water influx.

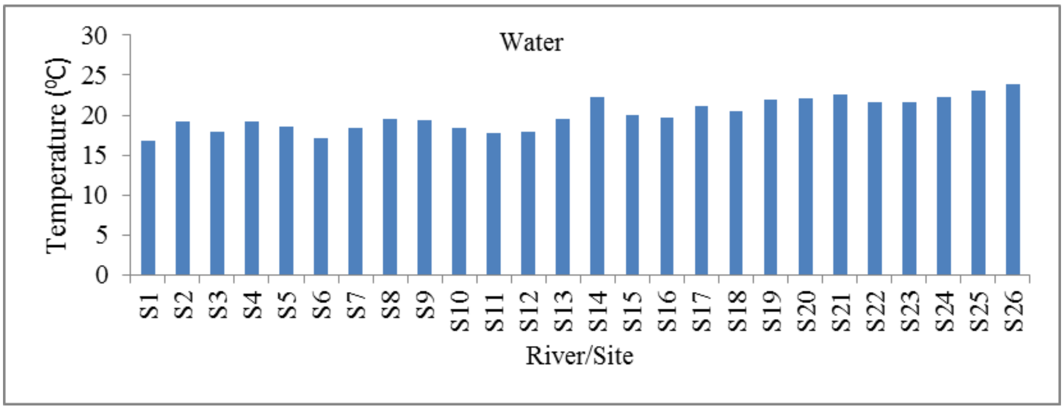

Figure 18. Temperatures of water

Hardness

The total hardness concentrations of the sampled rivers ranged from 0.1 mg/L to 5.96 mg/L, implying that the river waters are soft hence suitable for domestic, agricultural and industrial use (Figure 19). The hardness levels were below the acceptable limits in Kenya set by KEBS of 600 mg/L (KEBS, 2014). Total water hardness is a measure of dissolved minerals mostly calcium and magnesium in water and is expressed as milligrams per liter (mg/L) of calcium carbonate ($CaCO_3$). Water containing calcium carbonate at concentrations below 60 mg/L is generally considered as soft; 60–120 mg/L, moderately hard; 120–180 mg/L, hard; and more than 180 mg/L, very hard (USGS, 2016).

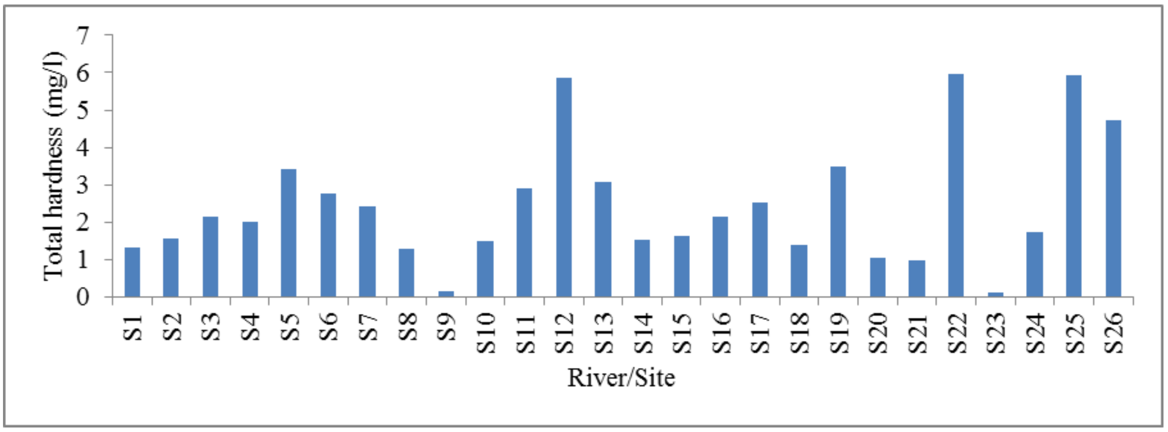

Figure 19. Total hardness in water

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

In this study, both BOD and COD levels had similar trends in the sampled sites with nearly all the sampled sites/rivers being within the acceptable limits in the environment. River Chepkaitet at Chepkaitet bridge, river Koitobos at Koitobos bridge and the larger river Nzoia near Webuye town had levels above the threshold value of 30 mg/l (BOD) and 50 mg/l (COD) permitted in the environment (NEMA, 2006) as shown in the figures 20, 21, 22 and 23. High BOD/COD levels in river Nzoia near Webuye town was attributed to industrial effluents from industries around the town and sewage treatment plants. For Koitobos and Chepkaitet sites, organic materials from highly fertilized farms and pesticides especially flowers and cereal maize farms in the area were the most likely causes of the high BOD/COD levels (Figures 20, 21, 22 and 23). In river water quality, BOD is mostly associated with wastewater from sewage systems while COD associated with industrial effluents. To reduce or manage high BOD/COD values, proper design of waste water and sewage treatment plants should be done especially aeration. Therefore, the waste water effluent and sewage discharges should be monitored in the affected areas as a way of reducing point source pollution in the rivers.

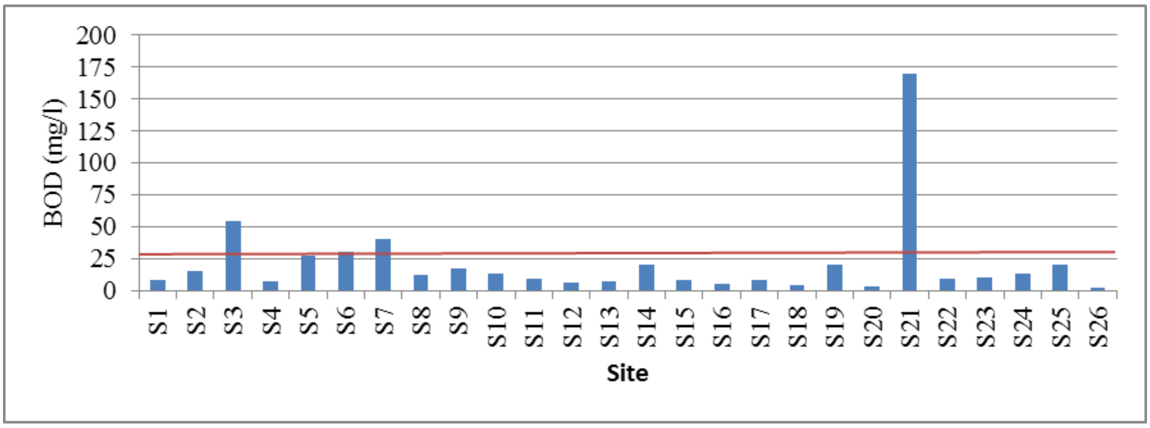

Figure 20. Biochemical Oxygen Demand (BOD) of water

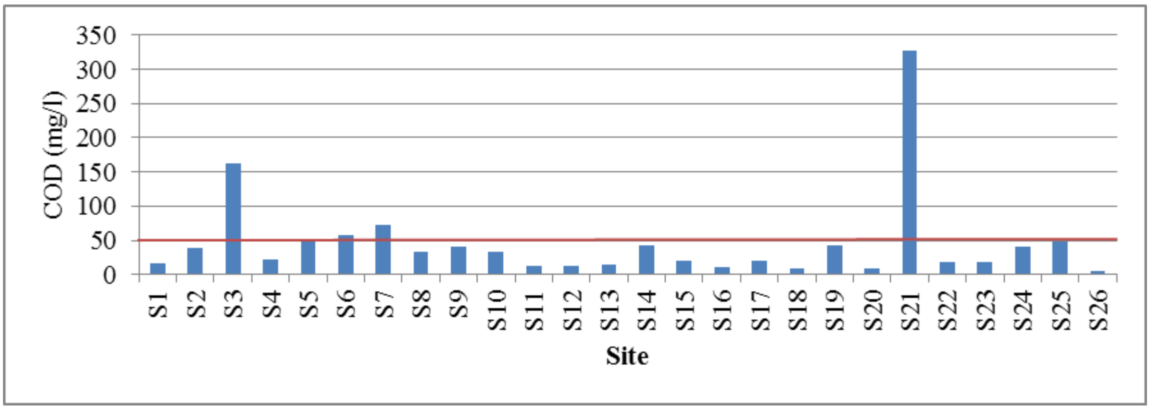

Figure 21. Chemical Oxygen Demand (COD)

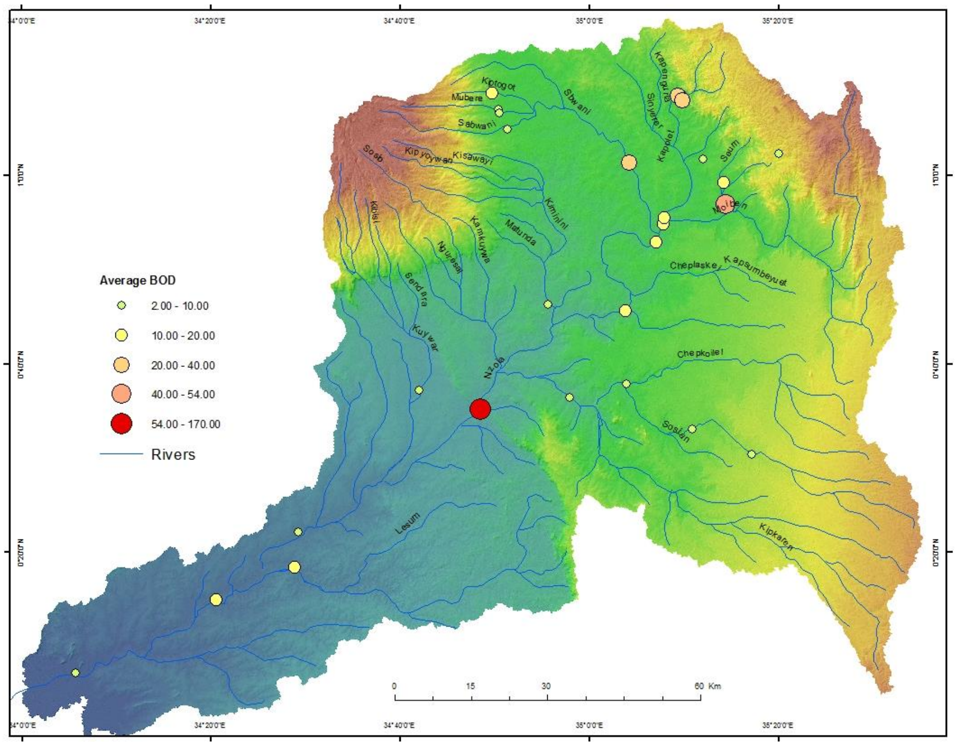

Figure 22. Pollution map for Biochemical Oxygen Demand (BOD)

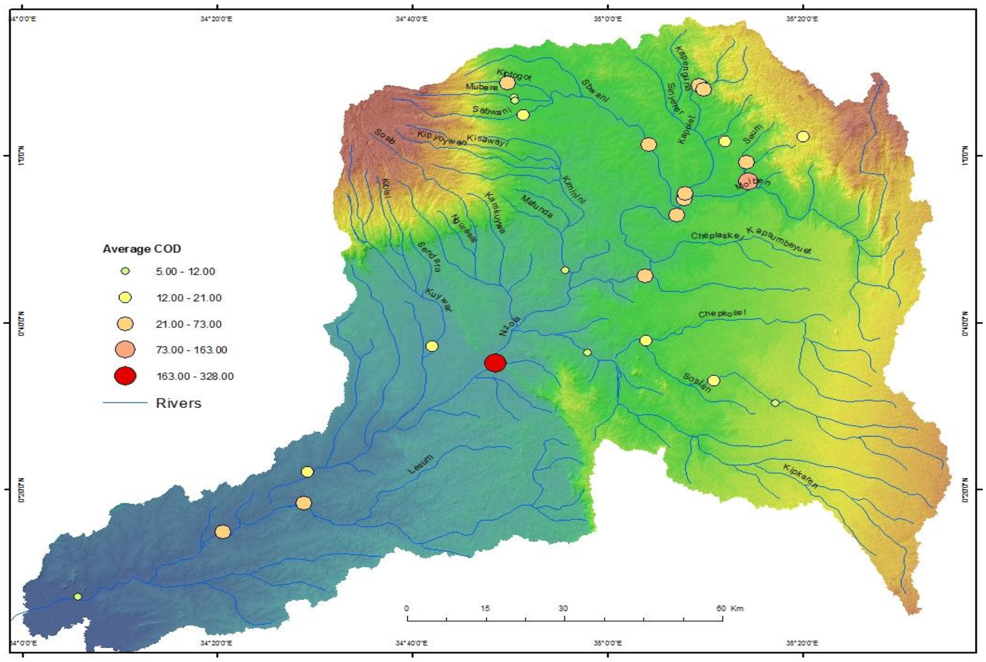

Figure 23. Pollution map for Chemical Oxygen Demand (COD)

Heavy Metals: Mercury, Cadmium, Arsenic, Chromium and Lead

In this study, the concentrations of mercury, cadmium and arsenic recorded from the sampled sites (concentrations of < 0.001 mg/L) were within acceptable limits set by KEBS of 0.01 mg/L for arsenic and cadmium, and by NEMA for mercury levels of 0.001 mg/L. These negligible concentrations can be attributed to the fact that there were few activities within the sampled sites that release these heavy metals in rivers. High levels of chromium were recorded in the River Nzoia near Webuye town (0.29 mg/L) and at Kipkaren town Bridge (0.073 mg/L) on River Kipkaren against maximum acceptable limits of 0.05 mg/L (KEBS, 2014) as shown in figures 24 and 25. This was attributed to point pollution by industries around Webuye town. At Kipkaren bridge, the river runs in the middle of township where all kinds of wastes are dumped into the river. The chromium in water could end up being consumed by fish and enter the food chain. When consumed by humans, chromium poses health risks including carcinogenic effects and kidney damage. The lead concentrations recorded for almost all the rivers (0.001 – 0.009 mg/L) were within the acceptable limits of 0.05 mg/L (NEMA, 2006) as shown in figures 24 and 25 Human exposure to lead causes brain damage, mental retardation lung cancer and could lead to death of unborn babies. These negligible concentrations can be attributed to the fact that there were no or few activities within the catchment that release lead in river waters.

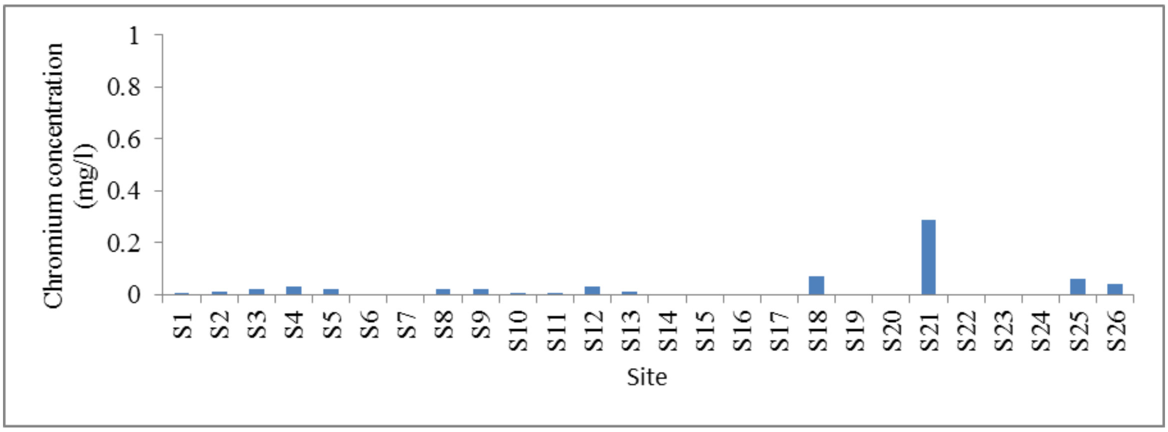

Figure 24. Chromium concentrations in water

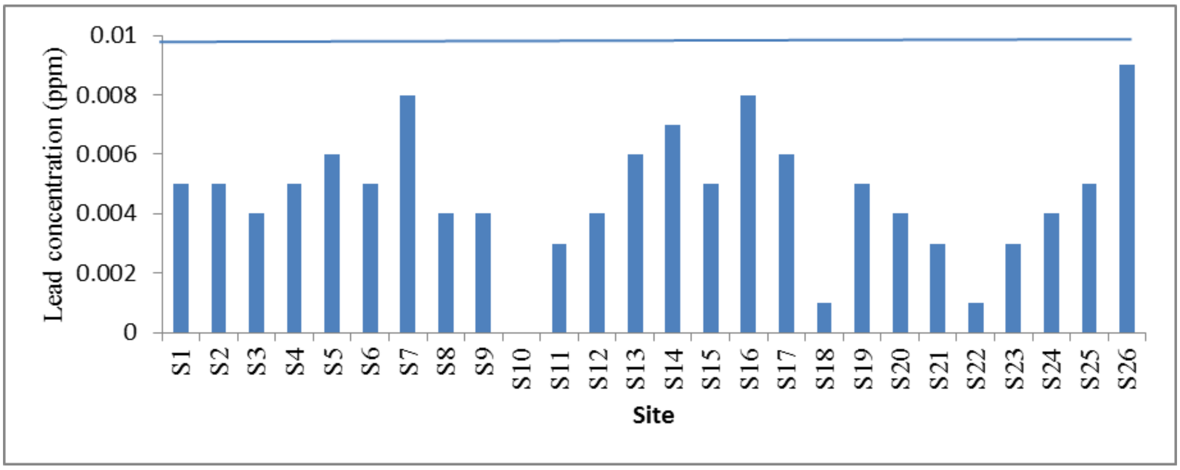

Figure 25. Lead concentrations in water

Zinc, Iron and Copper

In this study, zinc was recorded from all the rivers sampled (0.12 – 0.9 mg/L) with its values being within the acceptable limits of 1.5 mg/L (NEMA, 2006) as shown in Figures 26 and 27. Exposure of zinc to plants may lead to bio-accumulation thus posing health risks along the food chain. The majority of the rivers sampled had iron levels exceeding the allowable limits of 0.3 mg/l (KEBS, 2014). River Kuywa water treatment site near Bungoma town and River Nzoia at Sigomre bridge recorded the highest iron levels of 0.9 mg/l, followed by River Nzoia at Brigadier bridge in Soysambu (0.82 mg/l) (Figures 28 and 29). The high levels of iron were largely attributed to soil erosion carrying iron minerals to river waters. Intervention measures should include control of soil erosion to reduce the amounts swept in the rivers. For drinking water; filtration, ozonation, chlorination and use of water softeners should be taken in consideration to reduce potential health risks associated with consumption of such water. For sediments, all the sampled rivers had iron content ranging between 3000-4000 ppm except at the main source of river Nzoia (Kapolet North water treatment site) which had very little sediment mainly white sands (Figure 29). This was consistent with the iron content in water.

The 26 sampled sites recorded high concentrations of copper in water against the acceptable limit of 1.0mg/L (KEBS, 2014), with the highest concentrations of 2.78 mg/L and 2.4 mg/L recorded at River Nzoia at Webuye Bridge and River Nzoia at Sigomre Bridge respectively (Figure 30). The high levels of copper were attributed to high volume of water at the sites and therefore increased carrying capacities mainly erosion. In addition, point-source pollution from industries near Webuye town and farming activities in the surrounding areas are other possible sources. Copper is an essential trace nutrient required in small amounts by humans, plants and animals and therefore mitigating measures are necessary to reduce the high concentrations in the affected areas.

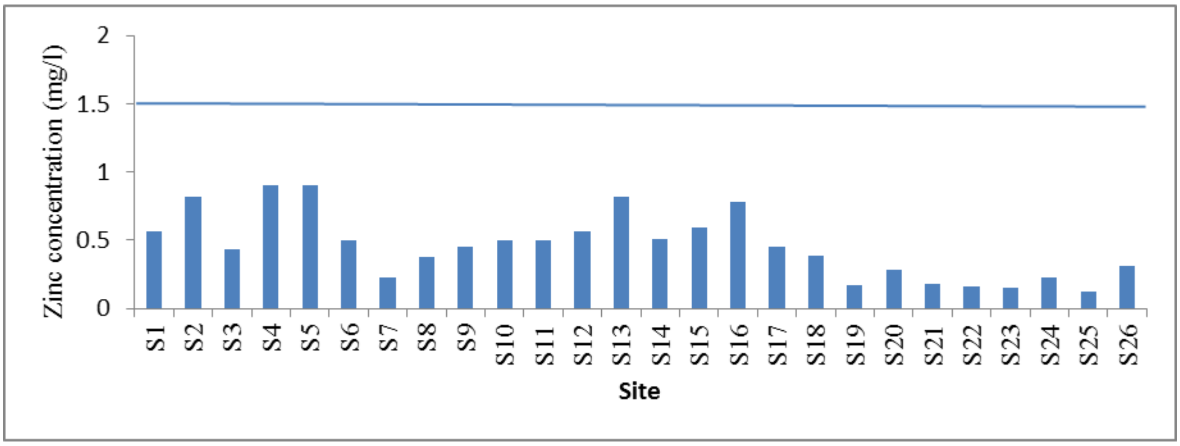

Figure 26. Zinc concentration in water

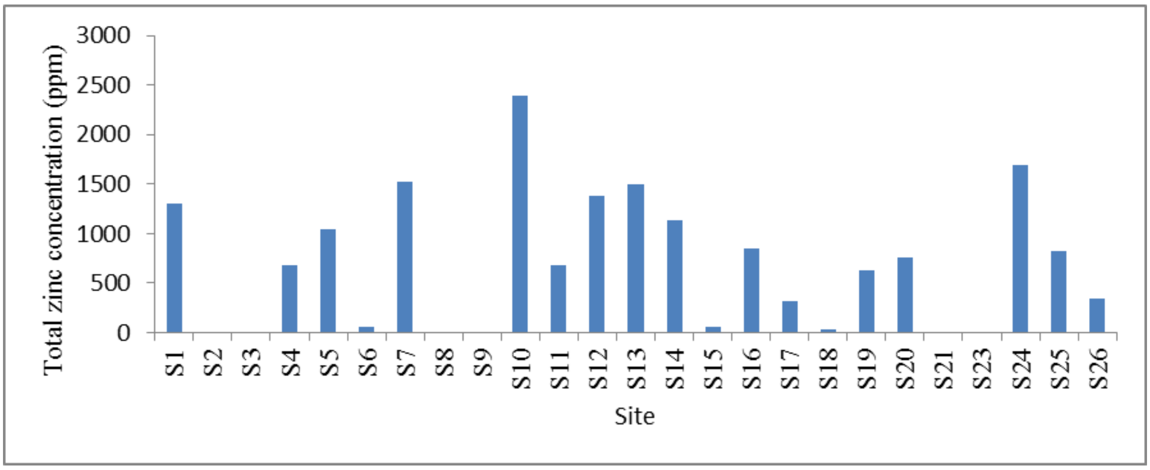

Figure 27. Total zinc concentration in sediments

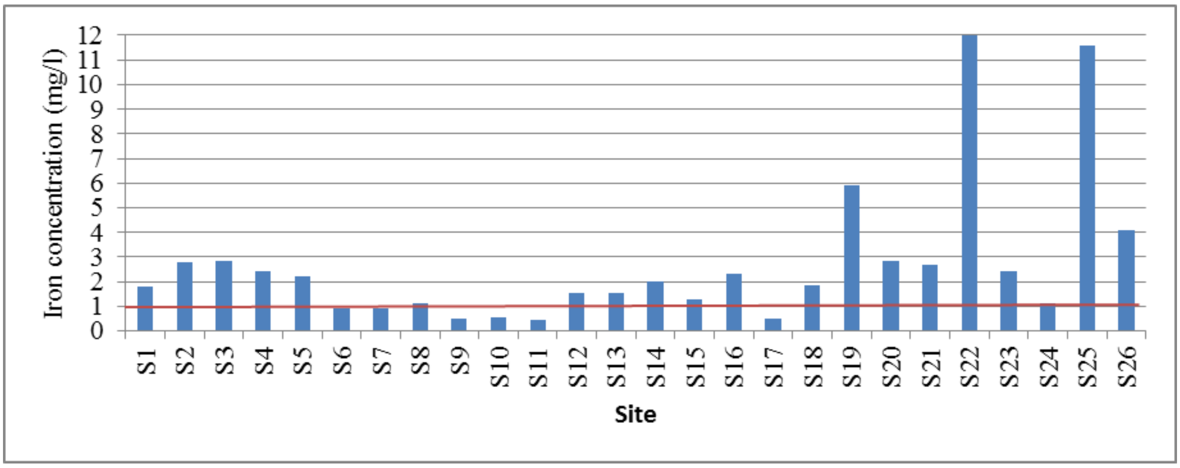

Figure 28. Iron concentration in water

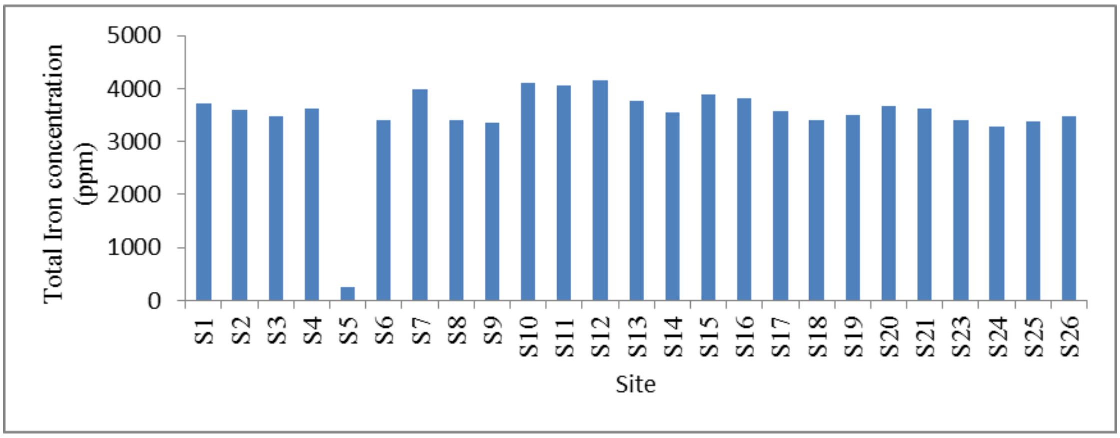

Figure 29. Total iron concentration in sediments

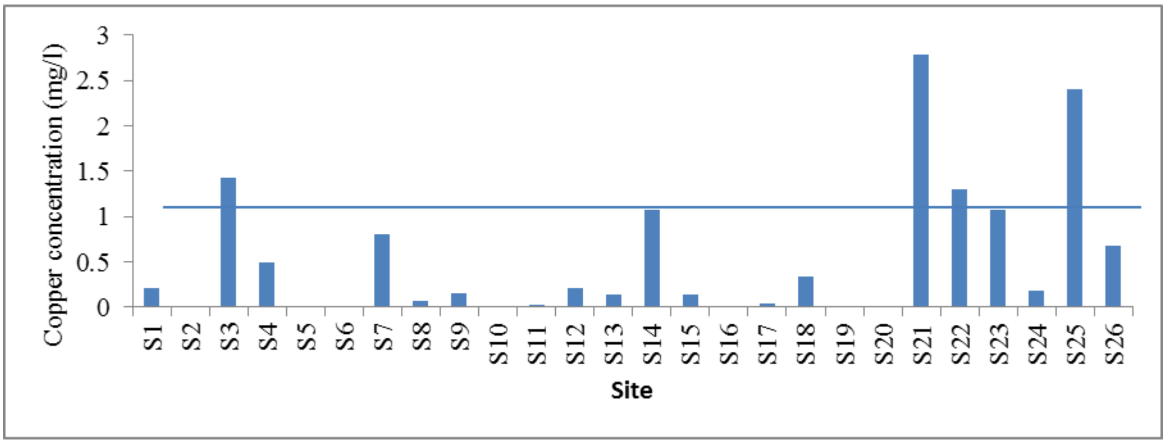

Figure 30. Copper levels in water

For sediments, Rivers Kiptogot, Mubere, Kaibey / Koitobos and Sabwani recorded high concentrations of copper i.e. 178.52 ppm, 189.59 ppm, 147.84 ppm and 92.47 ppm respectively (Figures 31). This was attributed to non-point pollution especially from highly intensified agricultural activities in this region majorly large scale flower and maize production. Copper is moderately soluble in water and binds easily to soil particles and organic matter. The levels of copper in sediments can provide an indication of the level of pollution of the river as the sediments act as permanent or temporary traps for materials present in the river. The effects of copper on aquatic life include fraying of fish gills and reduced olfaction function in fish.

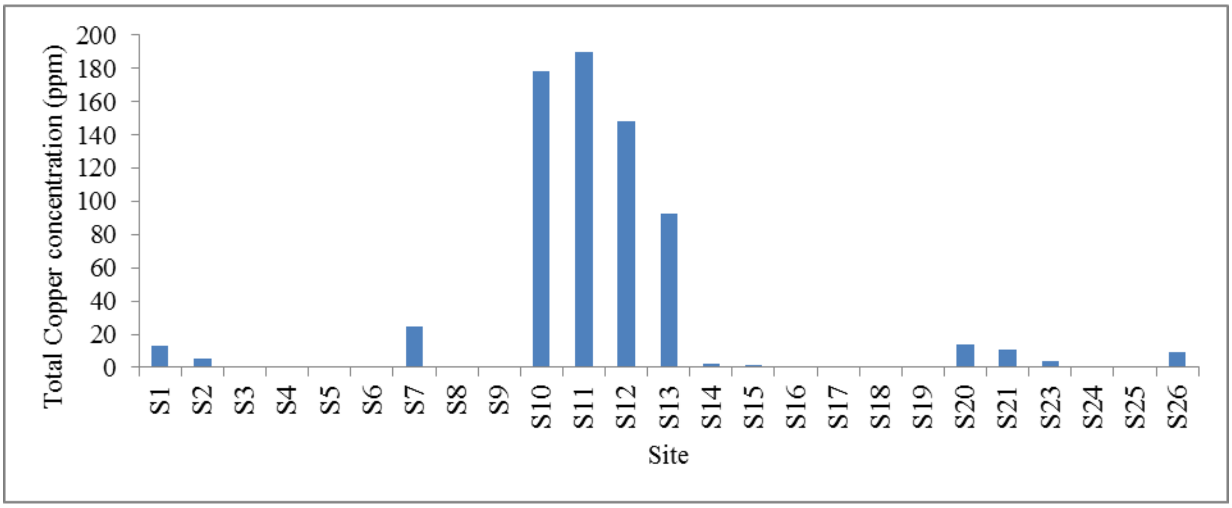

Figure 31. Total copper levels in sediments

Fecal and Total Coliforms

In this study, all the sampled sites had no fecal bacteria detected except in R. Kipkaren at Kipkaren Town Bridge (47 Cfu/100ml). This could have been caused by the high urban population in Kipkaren town and poor sewage drainage systems leading to the human and animal waste finding its way to the water.

Conclusion

All the rivers in the watersheds forming the River Nzoia catchment contained high levels of iron in water which exceeded permitted levels for environmental drinking standards. In addition, the turbidity levels of water were beyond accepted limits set for drinking water and acceptable environmental water standards. There was no pollution of water from heavy metals (mercury, cadmium and lead). River Nzoia near Webuye town and Sigomre bridge were the most polluted waters with levels of nitrates, iron, copper, chromium, BOD and COD exceeding the accepted limits in the environment. For sediments, the contents of copper, magnesium and iron were high in the upper catchment of river Nzoia (foot slopes of Mt Elgon). The levels of nitrates and phosphates in the sediments were high in the lower parts of the river Nzoia catchments. A wide range of interventions were proposed to manage point or non-point pollution sources which included land and soil conservation measures to reduce erosion and sedimentation, precise fertilization, proper sewage treatment and disposal, proper industrial effluent treatment among others. For point source pollution, the interventions especially for high BOD and COD levels in water should be aimed at monitoring possible pollution sources in the study area i.e. from nearby industrial effluent discharge sites sewage treatment systems and horticultural farms. To reduce or manage high BOD/COD values, proper design of waste water and sewage treatment plants should be done especially aeration. To reduce high turbidity, land and soil conservation strategies to control soil erosion at the sub-catchment levels is recommended. In addition, organic farming should be encouraged in the region to reduce use of chemicals (pesticides) which pollute rivers and conservation agriculture practices like minimum/zero tillage, crop rotation etc. to help conserve the soil and the environment.

Acknowledgement

The authors acknowledge the European Union (EU) for funding this study through the WaTER programme. Special thanks go to the Ministry of Water and Irrigation team of hydrologists from the Water Resources Department, for their valuable information about the hydrological network of the River Nzoia Basin.

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Population Structure of *Prunus africana* (HOOK.f.) Kalkm. and *Olea europaea* L. in South Nandi Afromontane Forest, Kenya

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Abstract

Prunus africana and *Olea eurpaea* tree species from the moist highlands of sub Saharan Africa are subject to great exploitation and therefore endangered due to their medicinal values and fine wood. Studying their population dynamics play an important role in identifying the conservation needs in tropical ecosystems. This paper focuses on an ecological study carried out in April-June 2017, within South Nandi Afromontane Forest, Kenya. The objectives were to analyze population density, diameter size class distribution and the horizontal structure of *Prunus africana* and O*lea europaea* species as indicators of the respective species stability within the forest. Two line transects established 250metres apart were used to lay twenty systematic sample plots of 50 m x 20 m each, a long a transect at an interval of 200 m.These sample plots were further divided into five sub sample units of 20 m x 10 m where the number of trees DBH (>10 cm), poles (5-10 cm), saplings (1-5cm) were assessed while the number of seedlings with DBH (<1 cm) were assessed in 50m x 1m bands within the sample plots. Two way ANOVA and Chi –square x^2 goodness test was applied at 5% level of significance. The population densities of *Prunus africana* and *Olea europaea* varied between 51 ha^{-1} and 34 ha^{-1} for the species respectively. Diameter size class distribution took the shape of reverse J curve which characterizes stable uneven aged forest stands. The horizontal structure was discontinuous for both species with clusters observed along the transects. Forest canopy gaps created by human activities, windfalls and fires characterized the forest and influenced spatial distribution of *P.africana* and *O.europaea* stands. Recruitment and regeneration of both species occurred more intensively in canopy gaps but displayed inhibition near mature conspecifics throughout the forest floor. Management planning based on the principle of multiple use embracing conservation and sustainable utilization, participatory and consultative management approach and putting in

place intergraded forest management plan, building on the proven traditional management system and provide a useful document for managing the forest and farmlands sustainably.

Keywords: Diameter; Horizontal structure; Recruitment; Regeneration; Tree density; Tropical forest; *Prunus africana*, *Olea europaea*

Introduction

African cherry (*Prunus africana* (Hook.f.) Kalkam and Wild olive (*Olea europaea* L.) tree species from the moist highlands of sub Saharan Africa are subject to great exploitation and therefore endangered due to their medicinal values and fine wood. *Prunus africana* is listed under CITES Appendix ll (Cunningham and Schippmann, 1997). Unsustainable management has led to decline in the populations due to subsistence bark harvests for medicinal trade (Stewart, 2001), coupled with illegal harvesting, settlements which has affected the integrity of the forest (Cunningham and Mbenkum, 1993). Even though several studies have been conducted on the adverse effects of tree over exploitation, few studies have examined their densities, population structure, size class distribution and regeneration status of *Prunus africana* and *Olea europea*. Knowledge of tree population dynamics is very important for understanding the conditions of recruitment and regeneration of a given species (Tesfaye, 2010).

Prunus africana is a member of the *Rosaceae* (subfamily *Amygdaloideae*) family with its highest density in temperate regions (Cronquist, 1981). *Prunus africana* is an important multipurpose tree species (Cunningham and Mbenkum, 1993); its bark is the only source of an important drug which is used in the treatment of benign prostatic hyperplasia besides other functions of the tree (Bombarddelli and Morazzoni, 1997). The bark extracts of *P. africana* have been used in treatment of benign prostatic hyperplasia for over three decades and the harvesting of this tree for bark extraction has resulted in the species becoming endangered (Bombardelli and Morazzoni, 1997). In the 1990s it was estimated that 35,000 trees sourced from largely from Cameroon, Madagascar, Kenya and Equatorial Guinea, were debarked annually. The extract from the bark is manufactured into various herbal products. The most popular product is the capsular form, sold under its former scientific name, *Pygeum africanum*. Currently *Prunus africana* bark is entirely collected from the wild, although attempts at cultivation are underway in Kenya (Dawson *et al*., 2017). Prior to the discovery in 1966 of its herbal remedy, *P. africana* was a relatively common, but never abundant montane species.

P. *africana* has a wide distribution in Africa. It occurs in montane regions of central and southern Africa and the islands of Bioko, Sao-Tome, and Grande Comore (Kalkman, 1965). *P*. *africana* is most abundant in open areas along forest margins and in disturbed areas (Ndam, 1996) as it is not shade-tolerant (Kiama and Kiyiapi, 2001). Ndam, 1996 also found most seedlings in forest gaps or fallow fields. This suggests that *P*. *africana* is a light-demanding, secondary-forest species. Because of deforestation at lower elevations, *P. africana* is confined to distinct "forest islands" that differ genetically (Barker *et al.*, 1994), with the Madagascar population being the most distinct (Martinelli *et al*., 1986). The tree occurs at altitudes between 1000 and 2500 m in montane forests (Sunderland and Tako, 1999). Distribution appears to be related to mean annual temperature and rainfall and/or cloud cover. Because of their relatively large areas of montane habitat, Cameroon and Madagascar contain the largest populations of the species. In Kenya, it is common in Mt. Kenya, Aberdares, Kakamega, and Cherangani Forests. It also occurs in Timboroa, Nandi, Tugen hills and western part of Mau Forest.

Olea europapea, commonly known as Olive tree is in the family of Oleacea. The wild olive tree, is a species widely distributed in dry forest in Ethiopia. It is found in dry forests and forest margins between 1250 and 3100 m a.s.l. and is usually around 15 m high though it can reach up to 25 m in height in some places (Friis, 1992). *Olea europapea* is a long-lived tree. It shows strong xeromorphic characteristics and as an adult tree it can survive dry microclimatic conditions (Coetzee, 1978). It is widely used for house construction, fences and for making household furniture. The bark, the wood, the leaves and the roots are burnt to produce a distinctive smoke used for fermenting and flavouring of traditional beverages "Tela" and "Irgo" (yoghurt). Olea also has medicinal value. In southeastern Ethiopia, the processed wood sap is used for curing skin disease and mental problems, and its smoke is used as an insect repellent (Demel, 1996). In Kenya root or bark decoction is used as a remedy for malaria (Beentje, 1994). Detailed medicinal values of Olea are presented by Rizk and Gamal, 1995. The diverse use of the species has led to its extensive exploitation over the years in Ethiopia and other East African countries (Dale and Greenway, 1961).

The regeneration of most of the dominant high forest species in the Afromontane zone is under shade of mature forest (Pohjonen, 1986). The formation of a seedling-sapling bank under the forest canopy is the major regeneration route (Demel, 1997). Therefore, studies of natural regeneration of the dominant species in dry Afromontane forests are relevant for rehabilitation and conservation purposes. Knowledge of factors influencing the dynamics in natural populations will lead to a better understanding of the regeneration processes of trees, and has practical applications in the management of forest tree species. Regeneration dynamics of tropical trees are still poorly known especially in the case of species of tropical dry forest. The early growth potential of *P. africana* and *O. europaea* is equally not documented especially for local provenances of South Nandi region. Due to limited knowledge in the species early growth potential, their cultivation has not been done in most parts of Kenya including the study area and therefore face extinction threat in the wild. This study assessed and determined the population density, diameter size class distribution and the horizontal structure of *Prunus africana* and *Olea europaea* in South Nandi forest.

Materials and Methods

Study area

The study was undertaken in South Nandi forest which was once contiguous with Kakamega forest and the two forests are still no more than a few kilometers apart at their closest points. Biogeographically, the forest is often considered an extension of Kakamega and it is in effect a transitional between the lowland forests of west and central Africa (the eastern most outlier of which is Kakamega) and the montane forests of west and central Kenya highlands. Rainfall ranges between, 1,600 to 1,900 mm/year depending on altitude thus classified as moist forest under FAO. The forest is drained by the Kimondi and Sirua rivers, which merge to form the river Yala flowing into Lake Victoria. The landscape is gently undulating between 10 to 40%, the altitude ranges between 1700 to 2000 m above sea level, with temperature ranging between 18 to 24^0C. The forest is underlain by granitic and basement complex rocks, which weather to give deep, well-drained, moderately fertile soils. The South Nandi area has high agricultural potential and human densities around, particularly to the west. However, it is higher in altitude than Kakamega and floristically less diverse. The continuous closed forest canopy comprises indigenous tree species such as *Tabernaemontana stapfiana*, *Macaranga kilimandscharica*, *Croton megalocarpus*, *C. macrostachyus*, *Drypetes gerrardii*, *Celtis africana*, *Prunus africana*, *Neoboutonia macrocalyx, Olea species* and *Albizia gummifera*. The forest generally has a rich biodiversity that include highlands bird community thus recognized as an important Bird area, others are reptiles and butterflies.

The forest adjacent communities are mostly farmers with major cash crops being tea and maize. The average size of land per household around the forest is 2.5 hectares however most households to the west have lesser land holdings hence there is a lot of pressure on the forest resources.

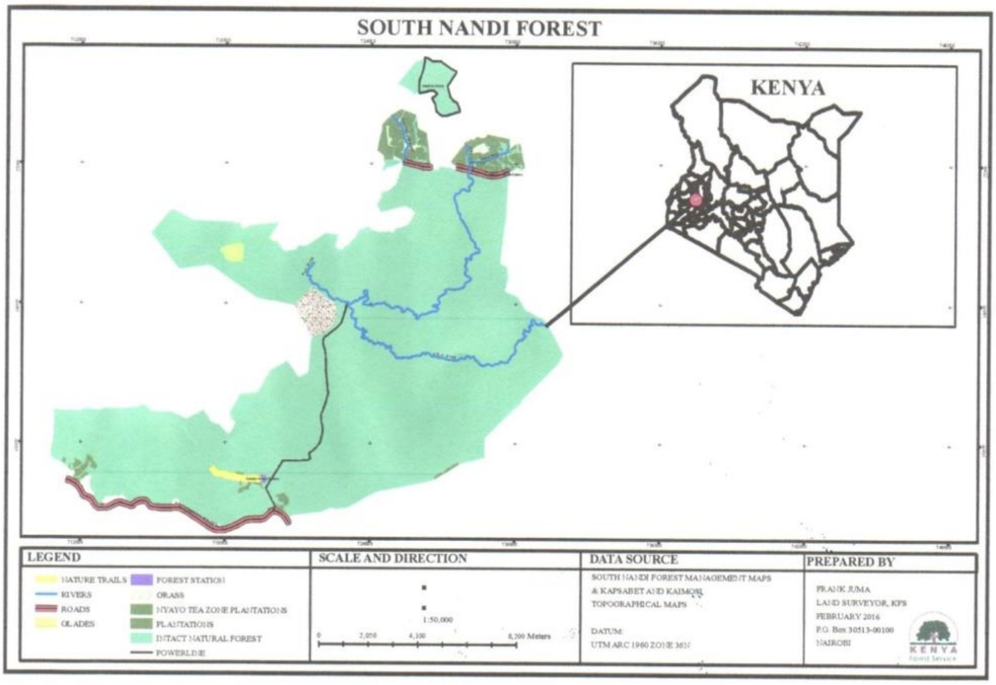

Figure 1. Map of South Nandi Forest, adapted from Kenya Forest Service.

Study species/ target population

The target population comprised of *P. africana and O. europaea trees* from South Nandi forest.

Sample and sampling procedures

Two line transect established 250 m apart and running parallel to each other in the north east direction were used to lay 20 systematic sample plots of 50 m x 20 m each, along the transects at an interval of 200 m. The sample plots were further divided into five sub sample units of 20 m x 10 m where the number of trees (DBH ≥ 10 cm), poles (5 cm ≤ DBH <10 cm), saplings (1 cm ≤ DBH < 5 cm) were assessed while the number of seedlings (DBH<1cm) were assessed in 50 m x 1 m bands within the sample plots as described by Hitimana *et al*., 2004.

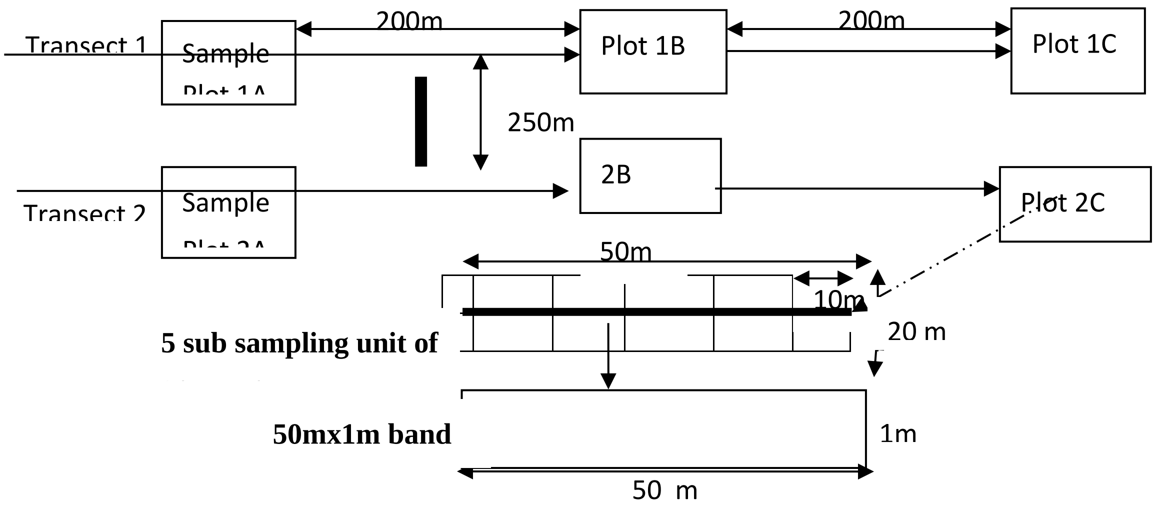

Figure 2. Diagram illustrating transect layout and sample plots design

Data analysis

The number of trees recorded for *P. africana* and *O. europaea* were used to determine each species density per hectare in the study area as follows;

$$\text{Density}= \frac{Total\ no.recorded}{Sample\ area\ (ha)} \text{ …..Formula 1.}$$

The number of trees per hectare for each DBH class recorded for *P. africana* and *O. europaea* were plotted against Diameter at Breast Height (DBH) classes to show the pattern of diameter size distribution for the two species in the study area. The observed DBH distribution was tested against the expected reverse j-curve for stable tree species populations. Two way ANOVA and Chi –square x^2 goodness test was applied at 5% level of significance (Kiernan, 2014) and then results compared to the hypothetical UNO 1994 model for structurally stable East African natural forests.

Results

Population densities of *Prunus africana and Olea europaea* in the study area

The densities of *Prunus africana and Olea europaea* tree species in each DBH class are presented in Table 1 and Table 2 respectively.

Table 1. Mean density (Individuals ha^{-1}) of *P. africana* in different categories

Variable	Sampled area/ha	No. of individuals in sampled area	Total no. of individuals in sampled area	Density ha^{-1} with respective % in bracket
Seedlings	0.2	174	578	870 (75.3)
Saplings	4	519	3629	130 (11.2)
Poles	4	418	3029	105 (9.1)
Mature trees	4	202	792	51 (4.4)

In Table 1 above**,** we recorded a total of 1,156 stems ha^{-1} for the *P.africana* variables in the study area. Seedlings were the most abundant and mature trees the least abundant, where 75.3% were seedlings (870 stems ha^{-1}), 11.2% were saplings (130 stems ha^{-1}), 9.1% were poles (105 stems ha^{-1}) and 4.4% mature trees (51 stems ha^{-1}).

Table 2. Mean density (Individuals ha^{-1}) of *O. europaea* in different size classes.

Variable	Sampled area/ha	No. of individuals in sampled area	Total no. of individuals in sampled area	Density $ha^{-1}$with respective % in bracket
Seedlings	0.2	116	577	580 (72.3)
Saplings	4	416	3,617	104 (13)
Poles	4	337	3,036	84 (10.5)
Mature trees	4	134	793	34 (4.2)

In Table 2 above a total of 802 stems ha^{-1} for *O. europaea* variables were recorded where seedlings were the highest and accounted for 72.3 % (580 stems ha^{-1}) while mature trees were the lowest with 4.2 % (34 stems ha^{-1}). The others were Saplings 13 % (104 stems ha^{-1}) and Poles 10.5 % (84 stems ha^{-1}).

The number of individuals for the two species in the sampled area ranged from 116 to 174 for seedlings, 416 to 519 for saplings, 337 to 418 for poles and 134 to 202 for mature trees. The density of mature trees with DBH >10cm varied from 34 stems/ha for *O. europaea* to 51 stems ha^{-1} for *P. africana* (Table 1 &2*)* and from 21stems ha^{-1} to 61 stems ha^{-1} along the transects and among the four sites (Chebilat, Kobujoi, Chepkongony and Kamarich).

We recorded significant differences in the densities of *Prunus africana* and *Olea europaea* across the study area as a result of interaction between the four sites(variable 1) and DBH Class(variable 2). Two way ANOVA indicates that there was a significant differences in the densities of *P. africana; F* (36.561), p=0.001<0.05) and *O. europaea.* F (20.512), P=0.001<0.05 among the DBH size classes in the four forest sites (Table 3 and 4).

Table 3. Tests of Between-Subjects effects for *P. africana*

Dependent Variable:VAR00003

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	7.507E6[a]	15	500494.933	1.102E3	.000
Intercept	5345344.000	1	5345344.000	1.177E4	.000
VAR00001	104454.000	3	34818.000	76.635	.000
VAR00002	7253472.000	3	2417824.000	5.322E3	.000
VAR00001 * VAR00002	149498.000	9	16610.889	36.561	.000
Error	21808.000	48	454.333		
Total	1.287E7	64			
Corrected Total	7529232.000	63			

a. R Squared = .997 (Adjusted R Squared = .996)

Table 4. Test of between subjects effects for *O.europaea*

Dependent Variable:VAR00003

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	3.130E6[a]	16	195612.983	2.987E3	.000
Intercept	1350912.657	1	1350912.657	2.063E4	.000
VAR00001	3133.022	4	783.256	11.961	.000
VAR00002	3080701.914	3	1026900.638	1.568E4	.000
VAR00001 * VAR00002	12088.759	9	1343.195	20.512	.000
Error	3077.750	47	65.484		
Total	5724583.000	64			
Corrected Total	3132885.484	63			

a. R Squared = .999 (Adjusted R Squared = .999)

The results shows that there were significant variation in the number of *P. africana and O. europaea* variables in the four sites. The frequency of the two species in each DBH class are presented in Figures 2 and 3.

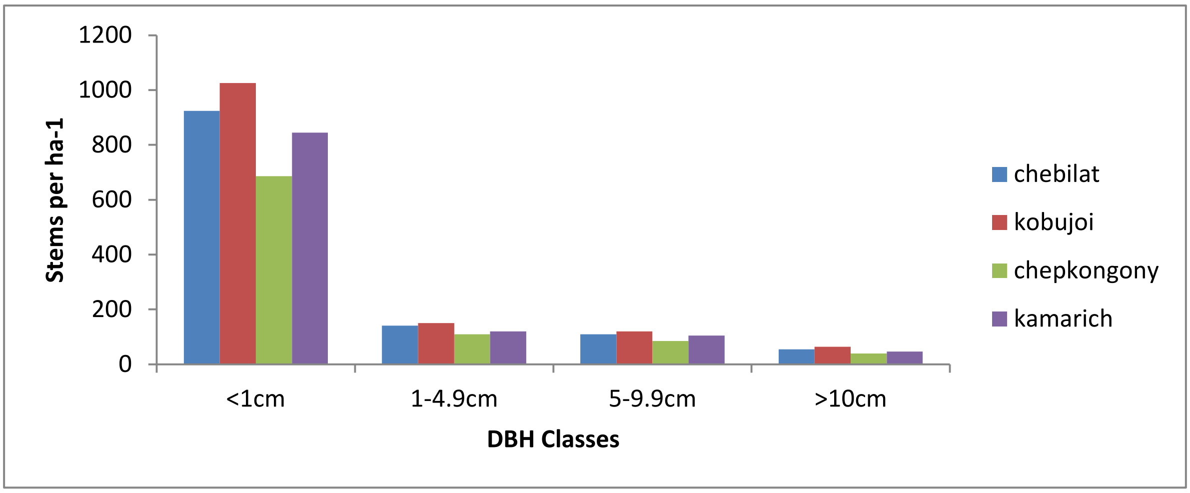

Figure 2. Frequency of *Prunua africana* in each DBH class in four sites

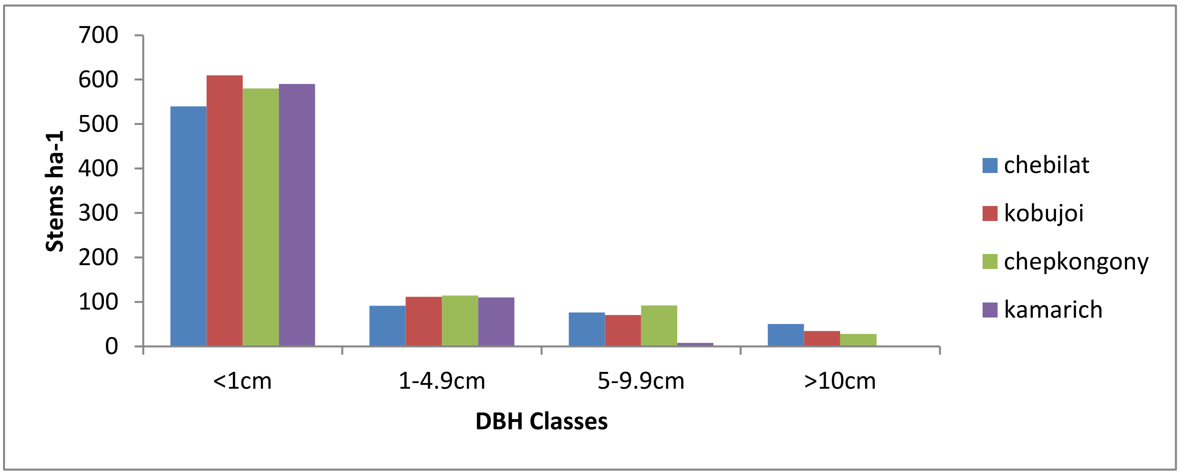

Figure 3. Frequency of *Olea europaea* in each DBH class in four sites

Evidence from the study shows that the seedlings of the two species survival to the sapling stages are extremely low at the few sites examined. Poor regeneration and recruitment into saplings, poles and mature trees was also observed and could be attributed to induced disturbance aspects like charcoal burning, uncontrolled grazing, wild fires and windfalls in the area. This is an indication that the population densities of these two species might continue to decline in the foreseeable future.

Population structure and regeneration

The population structure, distribution of variables in different size classes and regeneration patterns of the two species were analyzed and converted to densities per hectare as indicated in Figures 4 and 5 below.

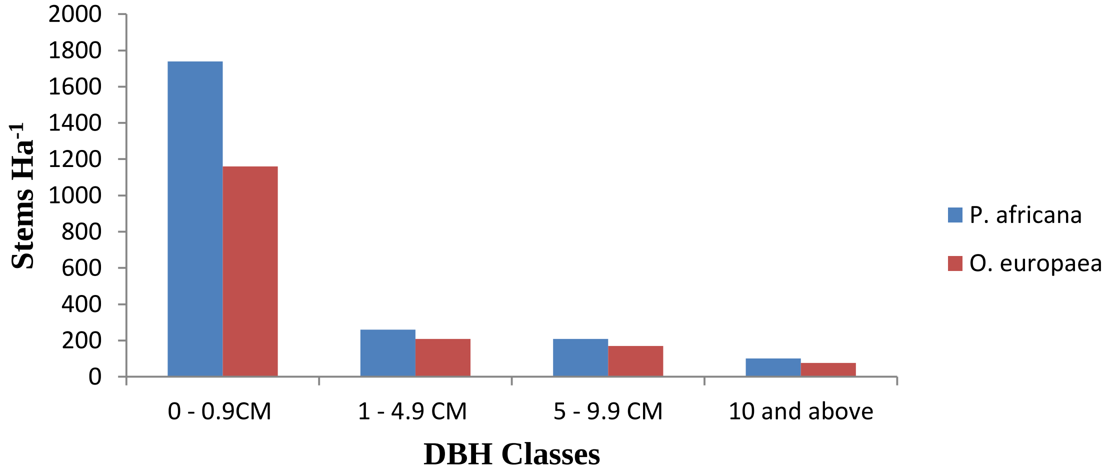

Figure 4. Population density of *P. africana* and *O. europaea* in different size classes

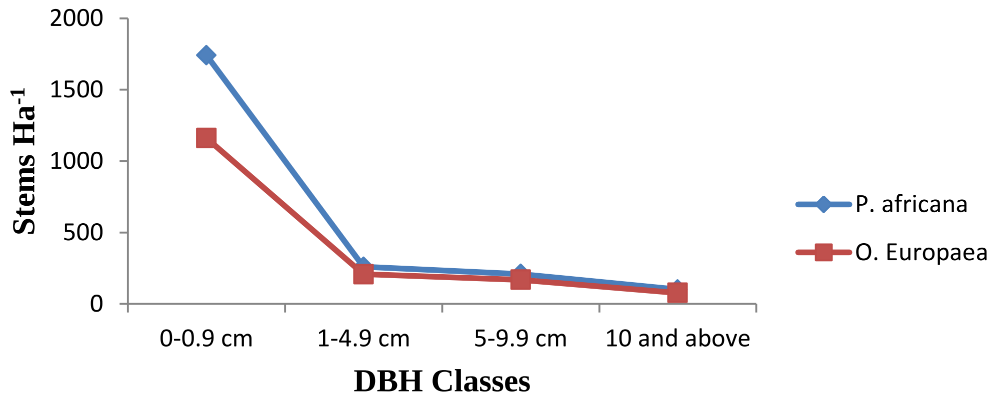

Figure 5. Diameter size class distribution profile for *Prunus africana* and *Olea europaea*

The population structure of *P. africana and O. europaea* had reverse j-shaped curve size class distribution with a smooth decline in the number of individuals from smaller to larger size classes (Figures 4 and 5), such a trend is an indication of a stable population that are naturally replacing themselves through good regeneration.

The density levels (No of stems ha^{-1}) for the two species in the study area were also low in comparison with the expected stocking level of a typical balanced stable East African natural forest (UNO, 1994) as shown in Figure 6.

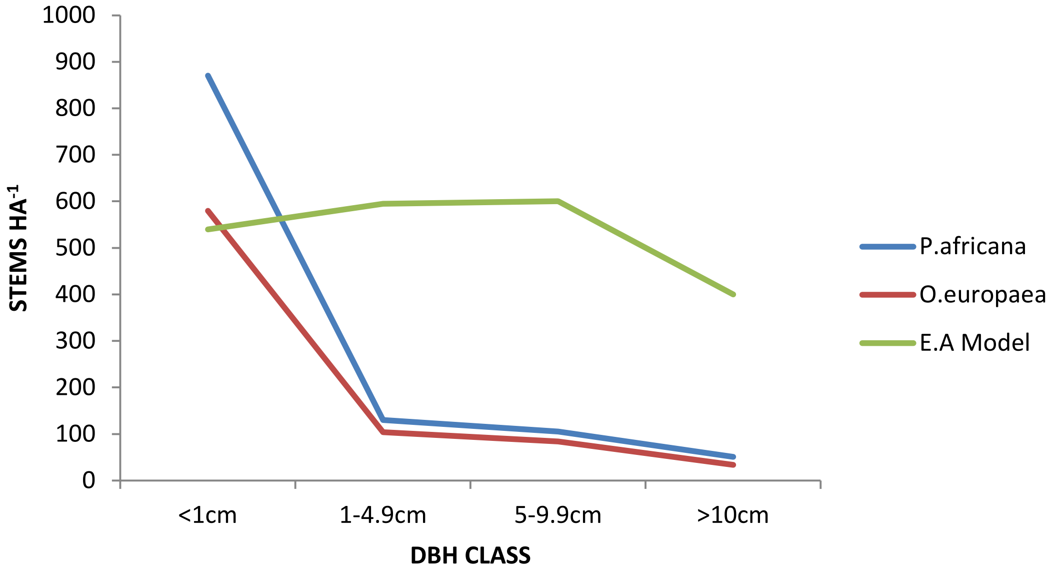

Figure 6. Diameter size distribution profile for *Prunus africana* and *Olea europaea* within South Nandi forest and its comparison with the hypothetical UNO (1994) model for structurally stable East African Natural forest

Discussion

Variation in stem densities within the forest could have resulted from clear fell and disturbance over the years, which normally leads to canopy gaps that stimulate growth of both herbaceous and woody plants that may suppress tree regeneration. The regeneration pattern of the tree species varied in the forest, this could be attributed to poor establishment as a result of low population and reduction in the densities of potential host trees that occurred due to human disturbance. Several other potential agents of low density of the two species noted include disease, insect attack and climatic fluctuation as per earlier studies by (Franklin *et al.*, 1987; Waring, 1987), Cunningham *et al.*, 2002).

Though seeds of the two species germinate in shaded conditions, the seedlings of *P. africana* appear to require light gaps in the canopy for survival to the pole stage. Insufficient human disturbance has not been sufficient to create light gaps for successful regeneration of *Prunus africana*, in addition the undergrowth which is believed to be a product of clearfell may play a part in inhibiting survival of *Prunus africana* and *Olea europaea* to saplings stage.

Conservation of *P. africana* and *O. europaea* offers a formidable challenge since the species appears to require disturbance for regeneration, yet at sites where disturbance is occurring, *P. africana* is often a target of bark harvesters engaging in unsustainable levels of exploitation (Cunningham and Mbenkum, 1993; Sunderland and Tako, 1999). To help meet the increasing demand for *P. africana* bark extract, there is need to start projects that will generate income to the locals which will reduce pressure on the natural forest population. Surrounding communities should be encouraged to establish *P. africana* plantations.

In developing forest management strategies for south Nandi forest, it would be important to focus on the protection of the two species from depletion by encouraging the community to explore alternative tree species with similar properties. The ongoing participatory forest management should focus on on-farm cultivation of these two species in the long term. Even though the trees grow slowly, their incorporation into agroforestry systems would eventually develop alternative stocks that would help in reducing the forest degradation and depletion of the two species. The regeneration patterns analyzed indicates that there is fluctuating forest regeneration as a result of natural phenomena besides human induced processes.

Conclusion and Recommendations

The population densities *of P. africana* and *O. europaea* trees in South Nandi Forest varied from 51 ha^{-1} and 34 ha^{-1} between the species respectively and the Intensity of use of the two species has resulted in over exploitation with ecological effect on the forest health.

Overall diameter distribution for the two species follow the reverse-J curve across the forest revealing a balanced pattern and were characterized by different regeneration trends and hence need for different management strategies that would ensure that the forest recover naturally. Management planning should be based on the principle of multiple use embracing both conservation and sustainable utilization, participatory and consultative management approach and putting in place intergraded forest management plan which would meet the needs of all stakeholders in the forest, building on the proven traditional management system of the local people and provide a useful document for managing the forest and the neighboring farmlands to ensure that the forest stable status is maintained.

Acknowledgements

Special thanks go to University of Kabianga for granting me the opportunity to undertake the study and Albert Baker Fund through Christian Science Church that financed part of this study. I would also like to express my deep gratitude to my supervisors: Mr Joseph Hitimana, Dr Peter Sirmah and Dr Thomas Matonyei for their guidance and constructive criticism that stimulated me to think broadly in many areas while undertaking this study. I acknowledge the staff of faculty of Natural Resources and Environmental Management, University of Kabianga, Kenya Forest Service, KEFRI and colleagues for the help, encouragement and assistance in various ways. I also thank my family for the prayers, love and financial support during this study. Last but not least I thank God the almighty for giving me the strength, knowledge, finance and good health that enabled me to undertake and complete this study.

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Evidence of Genetic Diversity and Taxonomic Differentiation Among *Acacia senegal* Populations and Varieties in Kenya Based on RAPD Molecular Markers

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Abstract

Acacia senegal is a multipurpose tree species that forms an essential component of many farming systems in Sub-Saharan Africa where it is commercially exploited for gum arabic production. However, the species is yet to be put to optimal production in some countries due to lack of adequate information on its population genetics and taxonomic delimitation. This study reports the use of 13 randomly amplified polymorphic DNA (RAPD) markers to determine genetic diversity and taxonomic relationships among 12 natural populations of *A. senegal* in Kenya. High genetic diversity was found for all populations. Mean gene diversity (He) for all populations was at 0.288 with effective number of alleles per locus (Ne) of 1.496. Analysis of molecular variance (AMOVA) revealed most genetic variations residing within (60 %) rather than among populations. However, significant differentiation was detected among populations ($\phi st = 0.130$; $P < 0.001$). Cluster analysis based on similarity coefficient delimited three main groups corresponding to the three putative varieties of *A. senegal* namely *senegal*, *kerensis* and *leiorhachis*. The RAPD technology suggested high genetic diversity within the species and taxonomically differentiated the three varieties, however, there was evidence of admixture among the varieties. For high quality gum production and better economic returns, gum arabic collections should be designed based on the varieties and their locations. Seed collections for tree improvement or conservation programmes should take into account the groups detected for quality controls.

Keywords: *Acacia senegal*, genetic diversity, polymorphism, taxonomy, gum arabic, Semi-arid.

Introduction

Arid and semi-arid lands (ASALs) covers more than half of African continent (Wickens *et al*., 1996). The ASALs are characterized by low annual rainfall, high temperatures and low soil fertility leading to frequent famines (Mark, 1997). However, these ecosystems sustain more than 75 % of the sub-Saharan Africa human population. Despite the low vegetation cover, forest destructions go unabated in these areas (Wickens *et al*., 1996). Global studies show that destruction of tropical forests worldwide has increased dramatically in recent decades (Bawa and Seidler, 1998), posing a significant threat to biodiversity and biological processes in the drylands (Young *et al*., 1996). In Kenya, ASALs cover over 80 % of the total land surface and support about 10 million people. These ecosystems also account for more than 70 % of the country's eco-tourism interests, 60 % of the nation's livestock, and up to 75% of wildlife population (Government of Kenya, 2005). These ecosystems are endowed with rich diversity of plant and animal resources that inhabitants have used and marketed locally for generations (Chikamai and Odera, 2002). Despite the abundant biodiversity, ASALs house many under-utilized tree species with great potential of improving living standards of the rural poor and revolutionizing the dryland economy. Among such species is *A. senegal,* which is the source of gum arabic, an internationally traded commodity (Chikamai and Banks, 1993).

Acacia senegal, also known as gum arabic tree, is a multipurpose tree belonging to the family Mimosoidae subgenus, *Aculeiferum* (Brenan, 1983; Maundu *et al.*, 1999; Arce and Banks, 2001). Taxonomically, the species has been identified to form four varieties (*kerensis*, *senegal*, *rostrata* and *leiorhachis*) with three of them (*kerensis*, *leiorhachis* and *senegal*) found in Kenya, sometimes closely distributed (Fagg and Allison, 2004). Generally, the species is commonly found in tropical and sub-tropical regions, from South Africa northwards to sub-Saharan Africa and some parts of Asia (Raddad *et al.*, 2005). In Kenya, the tree is found in the northern, eastern, rift valley and coastal regions, mainly in the dry *Acacia* - Commiphora bushland (Chiveu *et al.,* 2008). The species is highly demanded because of its multiple uses such as; source of food, traditional medicine and pharmaceuticals, preservation and improvement of soil fertility, rites and customs, in addition to gum arabic which is the key product (Luvanda *et al.,* 2006; Obua *et al.*, 2006; Okunomo and Bosah, 2007).

Research shows that the Kenyan gum arabic meets international standards. However, challenges in collection and maintaining high quality is hindering its smooth trade (Chikamai and Banks, 1993; Chikamai and Odera, 2002). Other challenges include the significant variation in biochemical characteristics that has been found across the gum arabic collection range (Anderson and Weiping, 1992; Chikamai and Banks, 1993; Chikamia *et al*., 1996). However, the reported variation on gum arabic biochemistry can be used as a source of material for quality improvement through selection. To establish and manage the species for improved gum arabic production, selections, breeding and multiplication of elite individuals with high quality characteristics is required. Such improvement can be achieved through knowledge and understanding of the available genetic diversity and how it is structured.

Some information on genetic diversity of Kenyan population of *A. senegal* is available, however, these are not sufficient and none has addressed the taxonomic challenge of the species varieties. For example, a study by Chiveu *et al*. (2008) using randomised amplified polymorphic DNA (RAPD) and inter-simple sequence repeat (ISSR) markers showed high genetic diversity with no differentiation among populations. This study did not analyse the whole range of the species distribution in the country. Another study by Omondi *et al*. (2010) using simple sequence repeats (SSR or microsatellite) also recorded high genetic diversity within the species, however, this study was limited to variety *kerensis* alone. To develop a reliable improvement programme for *A. senegal*, elaborate genetic diversity study that captures the three putative varieties and the whole species distribution range is necessary. This will reveal how the three varieties interact and how this could affect gum production (Chikamai and Banks, 1993).

The aim of the present study was, therefore, to assess the level of genetic diversity and determine taxonomic differentiations among *A. senegal* populations in Kenya. Implications of the findings on management and improvement strategy of the species genetic resources are discussed.

Materials and methods

Population Sampling

Three hundred and sixty individual trees of *A. senegal* representing the 3 putative varieties (*kerensis*, *senegal* and *leiorhachis*) were sampled from 12 natural populations in Kenya (Table 1). Healthy and clean leaf tissues were collected randomly from 30 adult trees per population at a distance of between 150 and 600 m apart depending on the size of the population and distribution of trees within the population. The leaf samples were dried in silica gel and stored at -20°C until DNA extraction.

Table 1. Locations and genetic diversity indices of the 12 populations of *A. senegal* in Kenya.

Population	Latitude	Longitude	N	Na	Ne	I	He	% P
Archers-post	00°39′52.7″	037°38′47.0″	30	1.564	1.475	0.403	0.272	75.6
Ngarendare	00°33′39.9″	037°20′45.3″	30	1.660	1.531	0.444	0.302	79.6
Daaba	00°32′00.2″	037°45′39.9″	30	1.776	1.570	0.485	0.329	88.0
Ntumburi	00º11'29.9"	037º30'46.7"	30	1.820	1.531	0.465	0.310	90.0
Kulamawe	00º33'32.8"	038º01'38.6"	30	1.680	1.497	0.414	0.281	76.8
Kajiado	02°02′59.5″	036°47′48.8″	30	1.692	1.487	0.425	0.283	84.0
Kibwezi	02°12'14.2″	038°03′17.4″	30	1.716	1.545	0.462	0.313	84.8
Magadi	01°32′04.3″	036°33′45.5″	30	1.556	1.456	0.374	0.255	67.2
Taita	03°27′01.1″	038°28′39.5″	30	1.760	1.470	0.427	0.281	86.8
Rimoi	00º39'52.5″	035º34'16.4"	30	1.640	1.470	0.404	0.273	73.6
Marigat	00°28′20.4″	035°55′10.6″	30	1.528	1.379	0.360	0.234	76.4
Koriema	00º26'12.5″	035º52'02.9"	30	1.728	1.545	0.472	0.318	86.4
Overall mean			30	1.677	1.496	0.428	0.288	80.8

N-sample size, Na-Number of alleles per locus, Ne-Number of effective alleles per locus I-Shannon's diversity index, He-expected heterozygosity, % P-Percentage polymorphism

DNA extraction and PCR amplification

Genomic DNA was isolated from leaves following a modified CTAB procedure (Fernández *et al*., 2000). DNA was quantified through comparison with low DNA mass ladder (Invitrogen) stained in ethidium bromide-stained 2% agarose gels. Forty random primers were screened for amplification using 30 DNA samples from across the populations. Thirteen of the primers showed clear and analysable bands. Polymerase chain reaction (PCR) amplification was performed using the 13 primers in a 25µl reaction volume containing 1XPCR buffer (10 mM Tris-HCL pH 8.3, 50 mM KCl, 1.5 mM $MgCl_2$), 200mM each of dNTPs, 20 µM of primer, 0.5 units of Taq-polymerase (Invitrogen) and about 25 ng DNA template. The PCR amplification was performed using TECHNE TC - 412 Thermal Cycler (UK), with an initial denaturation at 94.5 ºC for 5 min., followed by 40 cycles. Each cycle consisted of denaturation at 94 ºC for 45 s, primer annealing at 37 ºC for 1 min, and extension at 72 ºC for 2 min with a final extension at 72 ºC for 5 min. PCR products were separated on 1.5 % agarose gel in 0.5 X TBE (Tris–Borate EDTA) buffer and stained in ethidium bromide

(10mg/ml). The sizes of the amplified fragments were determined using a 100-bp DNA ladder (Invitrogen) run along the sides of the amplified products. The amplified products were visualized under ultraviolet light and photographed using Gel LOGIC 200 imaging system (Kodak MI SE).

Statistical analysis

Amplified DNA fragments (RAPD profiles) were scored for each individual as discrete characters and transformed into binary matrix (1 = presence, 0 = absence) across all individuals from all populations and for each primer used. Table 1 shows chosen parameters for genetic diversity test. Percentage of polymorphic loci was calculated for each population. Shanon's diversity indexes (I) and expected heterozygosity (He) was also determined. Nei's unbiased genetic distance (*D*) was determined using POPGENE 1.32 software (Yeh *et al*., 1997). The Nei's genetic distance matrix was used to generate the phylogenetic tree using unweighted pair group arithmetic average (UPGMA) method in MEGA software (Tamura *et al*., 2007). The reliability of this phenogram was evaluated by bootstrapping the data matrix.

The hypothesis, that populations are differentiated because of isolation by distance, was tested by correlating Nei's unbiased genetic matrix against the geographical distance matrix. Spearman's rank correlation coefficient was calculated and significance determined with 10,000 permutations using Mantel procedure (Mantel, 1967) available in GenAlEx 6.4 software (Peakall and Smouse, 2006). To analyze the intra- and inter-population genetic variation, analysis of molecular variance (AMOVA) was performed using GenAlEx 6.4 software (Peakall and Smouse, 2006).

Results

Genetic diversity

Among the 40 random primers screened, 13 produced unambiguous, polymorphic and reproducible fragments while the others resulted to, either no amplification or smeared profiles, which could not be interpreted. The 13 primers yielded 250 bands (loci) with 243 (97.2%) being polymorphic. The band sizes ranged from 150 to 1500 bp. The number of amplified fragments per RAPD primer ranged from 15 (KFP 34) to 22 (KFP 10 and KFP 30) with an average of 19 bands per primer (Table 2). This set of loci is expected to give a good sampling of the total genome and a good assessment of the genetic diversity. The typical example of the polymorphism detected with primer KFP 8 is as shown (Figure 1).

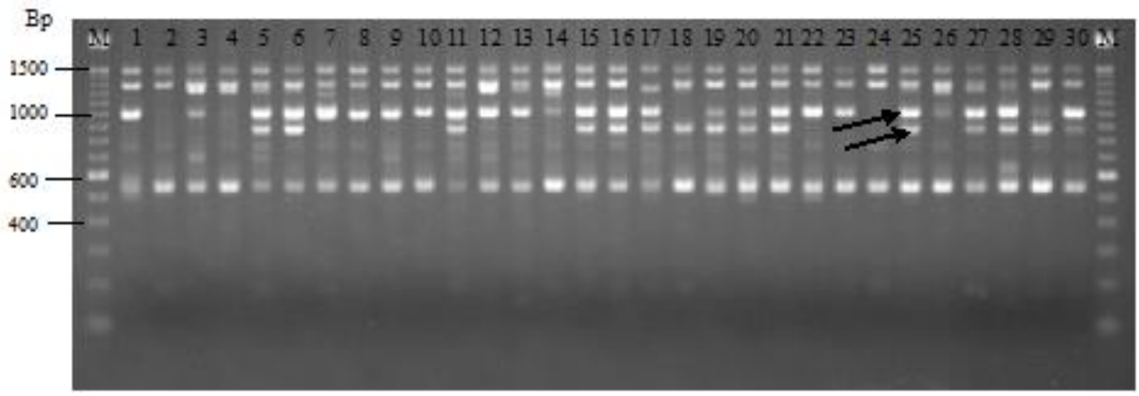

Figure 1. DNA banding profiles of 30 *Acacia senegal* samples from Daaba population using KFP 8 primer; arrows show polymorphic bands.

Distribution of total RAPD bands among populations appear to be highly constant (191-230 bands). Overall, the level of genetic diversity as shown by Shanon's diversity index (I) was relatively high varying from 0.360 (Marigat) to 0.485 (Daaba) with mean of 0.428. Based on mean percentage polymorphism (% P), diversity ranged from 67.2 % (Magadi) to 90 % (Ntumburi) with the overall mean of 80.8 %. Expected heterozygosity (He) ranged from 0.234 (Marigat) to 0.329 (Daaba). Effective number of alleles (Ne) ranged from 1.456 (Magadi) to 1.570 (Daaba) with a mean of 1.496 (Table 1). When the samples were considered putatively as varieties, the following diversity indices were observed; Ne (1.508, 1.495 and 1.477), I (0.441, 0.430 and 0.394), He (0.296, 0.288 and 0.268) and % P (83.5, 81.9 and 72) for variety *senegal*, *kerensis* and *leiorhachis*, respectively. Very few bands were unique to a single population. The 13 primers detected only 2 unique bands in 2 populations, one from Kibwezi and the other in Koriema.

Table 2. Characteristics of random oligonucleotide primers used in the study

Primer	Sequence	%GC	NB	%P	I	He
KFP 8	ACGCGCTGGT	70	21	98.6	0.571	0.356
KFP 10	ACGGTGCGCC	80	22	98.6	0.61	0.389
KFP 22	TACGCACACC	60	20	98.9	0.595	0.397
KFP 23	GCTCGTCAAC	60	17	92.8	0.552	0.376
KFP 25	ACTCGTAGCC	60	21	96.1	0.498	0.363
KFP 30	GTGCGGACAG	70	22	98.3	0.592	0.410
KFP 34	GTCCGTGCAA	60	15	98.3	0.56	0.401
KFP 35	CGTAGCCCCG	80	21	98.8	0.535	0.385
KFP 42	GGTCGGAGAA	60	18	96.1	0.568	0.381
KFP 45	GGAAGTCGCC	70	21	96.9	0.584	0.383
KFP 46	AGTCGTCCCC	70	19	96.7	0.572	0.372
KFP 48	CTGCATCGTG	60	17	97.2	0.564	0.375
KFP 49	GAAACACCCC	60	16	96.1	0.577	0.377
Mean			**19**	**97.2**	**0.568**	**0.382**

*NB, number of bands

Genetic structure

In assessing relatedness of the populations, Nei's unbiased genetic distance (*D*) was used. The shortest distance was recorded between Kulamawe and Magadi (0.020) populations while the largest distance (0.349) was between Magadi and Koriema populations (Table 3). Analysis of molecular variance (AMOVA) revealed higher significant genetic variation within populations (60 %; $P < 0.001$) than among the populations (27 %; $P < 0.001$).

Table 3. Unbiased Nei's pairwise genetic distance matrix between populations of *Acacia senegal* in Kenya.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	0.000											
2	0.177	0.000										
3	0.109	0.082	0.000									
4	0.332	0.184	0.288	0.000								
5	0.078	0.211	0.141	0.304	0.000							
6	0.349	0.201	0.304	0.020	0.311	0.000						
7	0.178	0.170	0.098	0.339	0.168	0.349	0.000					
8	0.111	0.174	0.162	0.275	0.060	0.287	0.182	0.000				
9	0.168	0.162	0.089	0.338	0.156	0.348	0.051	0.182	0.000			
10	0.209	0.284	0.273	0.292	0.237	0.305	0.304	0.288	0.297	0.000		
11	0.097	0.219	0.141	0.349	0.124	0.374	0.174	0.128	0.148	0.232	0.000	
12	0.188	0.115	0.207	0.182	0.214	0.186	0.279	0.165	0.283	0.257	0.205	0.000

*1-Koriema, 2-Ngarendare, 3-Daaba, 4-Kulamawe, 5-Ntumburi, 6-Magadi, 7-Kibwezi, 8-Kajiado, 9-Taita, 10-Rimoi, 11-Marigat, 12-Archers-Post

When the populations were grouped as varieties, 13% (P < 0.001) of the variance was attributed to the varietal differences. The AMOVA results is an indication of significant population differentiation as also shown by ϕst values (0.130; P = 0.000, 0.314; P = 0.000, 0.403; P = 0.000) for among varieties, populations and within populations respectively (Table 4).

Table 4. Analysis of molecular variance (AMOVA) of 360 individuals of *A. senegal* trees from twelve natural populations in Kenya using 13 RAPD primers. DF-degrees of freedom, ϕst-population differentiation

Source of variation	DF	Sum of Squares	Estimated variance	% variation	ϕst-Value	*P*-value
Among varieties	2	2803.539	7.882	13	0.130	0.000
Among populations	9	4812.942	16.617	27	0.314	0.000
Within populations	348	12614.767	36.249	60	0.403	0.000
Total	359	20231.247	60.749	100		

Genetic relationships among the 13 populations were summarized using cluster analysis as shown in Figure 2. The dendrogram grouped *A. senegal* into three major clusters concurring with the three putative varieties. A Mantel test comparing Nei's unbiased genetic distance and geographic distance matrices showed positive non-significant correlation (r = 0.007, P > 0.05). This indicates that differentiation amongst populations did not reflect their geographic locations.

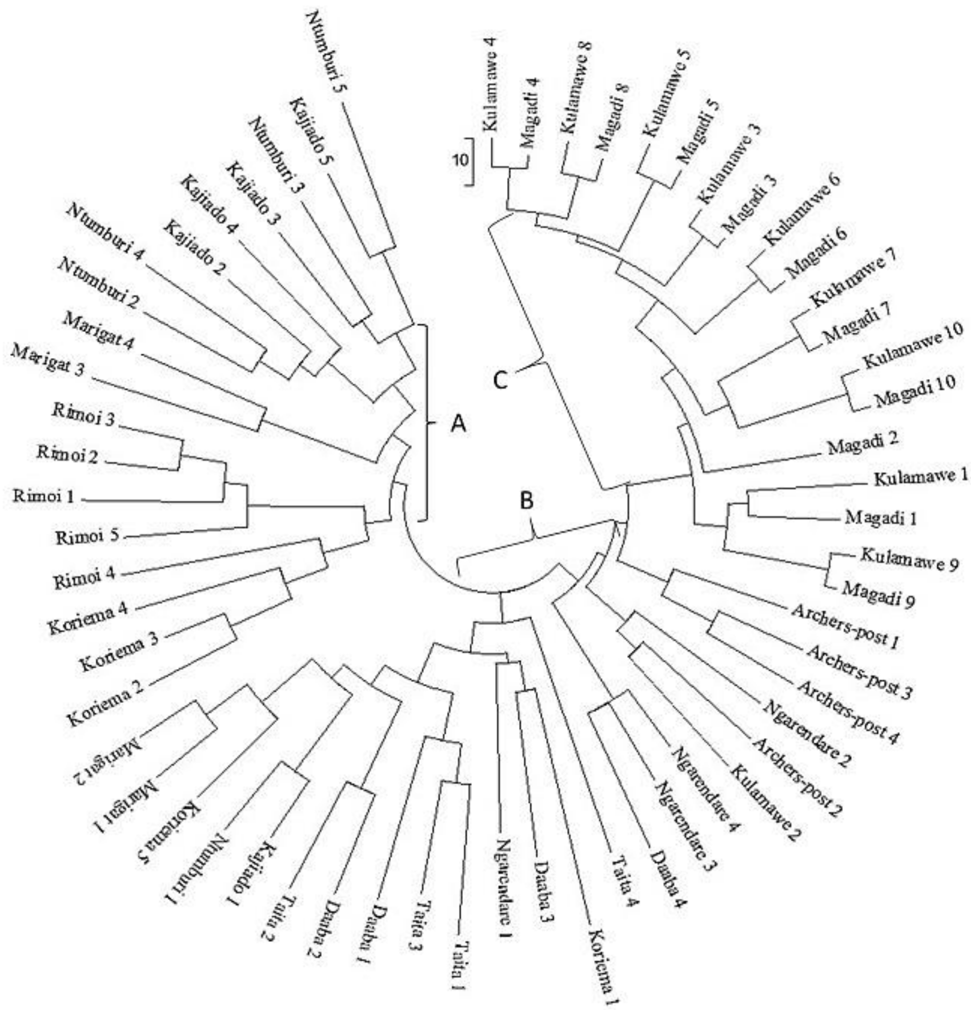

Figure 2. Cluster analysis of the 12 populations of *Acacia senegal* in Kenya showing the differentiation of the three varieties. A, variety *senegal*; B, variety *kerensis*; C, variety *leiorhachis*

Discussions

Genetic diversity

Overall in the present study, Kenyan population of *A. senegal* has revealed high genetic diversity. Assessment of genetic variability among individuals and populations using RAPD markers is promising because many polymorphic loci can be obtained in a relatively shorter time inexpensively without any prior knowledge of the genome of the species under study (Chiveu *et al*., 2008). In the present study, RAPD analysis was found to be important and a powerful tool for detection of spatial genetic variation. With 13 random primers, 243 polymorphic loci were obtained and differentiated the 360 individuals of *A. senegal* studied reflecting a rich allelic diversity in the populations.

The high genetic diversity detected in this study reflected in allelic richness, percentage polymorphism and heterozygosity is important in sustainable use of the species genetic resources. The diversity found is comparable to those reported for the species by Chiveu *et al*. (2008) and other tropical species such as *Vitellaria paradoxa* (Bouvet *et al*., 2004), *Acacia melanoxylon* (Playford *et al*., 1993) and *Araucaria araucana* (Bekessy *et al*., 2002). The high values of genetic diversity may be attributed to life history of the species and its spatial distribution, and are in agreement with the general conclusions already made on other widespread, long lived and out-crossing insect pollinated tree species.

Acacia senegal is widely distributed in the drylands and its adaptation to the varied environment requires high genetic diversity. Findings of the present study also corroborates high genetic diversity reported earlier by Chevalier *et al*. (1994) on the species using isoenzymes. They concluded that the significant heterozygosity observed in *A. senegal* and partitioning of higher percentage of genetic diversity within population suggests presence of exclusive out-crossing mating system. Such mating pattern promotes inter-breeding and genetic diversity. Additionally, high genetic diversity in tropical trees such as *A. senegal* may be attributed to high levels of gene flow among populations through seed and pollen movements (White *et al*., 2002). Other traits such as self-incompatibility has also been reported for *A. senegal* that may be ensuring diversity among individuals within populations (Doligez and Joly, 1997). Such variations are important in conservation biology and improvement programmes since they contain the future evolutionary adaptations and value addition opportunities (Shretha *et al*., 2002).

Forest trees are non-mobile and long-lived organisms, which grow under environmental conditions that are heterogeneous in time and space. Moreover, they are exposed to many stress factors, most of which are due to human activities, pollution, climate change, habitat fragmentation amongst others (Whitmore, 1997). For survival, higher genetic diversity is required. In this study *A. senegal* has shown high adaptive and improvement potential revealed through its high genetic diversity needed to survive, persist over time and avail opportunities for selection. The species is highly valued for its gum arabic production and potential economic stay for arid areas. Therefore, higher diversity presents chance for improved and sustainable utilization. Among the populations studied, higher level of genetic diversity was observed among the widely dispersed populations while the more restricted such as Magadi population had the lowest level of variation. As has been reported in other studies, distribution range and population size has a major correlate of within population genetic variation in tropical tree species with restricted populations showing less variation than those with broader distribution (Loveless, 1992). This scenario explains the present findings.

Genetic structure and variety differentiation

Plant species differ markedly in the way genetic diversity is partitioned between populations. These patterns are correlated with mating systems and life history parameters (Hamrick and Godt, 1989). Distribution of variability between and within populations in the present study based on nested analysis of molecular variance indicates that most of the genetic variation is present within populations (60%). This result was expected with the biological characteristic of *A. senegal*. Hamrick *et al*. (1991) identified those characteristics of species, which can explain high level of genetic diversity within populations and low levels among populations. These include life history, dispersal mechanism, mating systems and distribution range. Species such as *A. senegal* that do not have strong habitat specificity and are continuously distributed are expected to have more within-populations diversity than those with strong habitat preference and a scattered distribution.

Association between breeding systems and levels of genetic diversity has been well documented. Generally, most selfing species are characterized by high genetic differentiation among population whereas predominantly out-crossing wind pollinated species exhibit less variation among populations (Loveless and Hamrick, 1984). *Acacias* are generally out-crossers (Ross, 1979; Oballa, 1993). However, significant variation was detected among populations of *A. senegal* in this study. This is contrary to the common belief about the out-crossing woody perennial plants (Hamrick, 1990). In this regard, the high degree of population differentiation realized here is unlikely to be a result of inbreeding. Pollination trials on *A. senegal* have shown that the species is exclusively out-crossed and self-incompatible (Tandon and Shivanna, 2001). Differentiation among populations of *A. senegal* could therefore be attributed to taxonomic difference within the species whereby four putative varieties (*rostrata*, *kerensis, senegal* and *leiorhachis*) have been recognized. Three of these varieties (*kerensis, senegal and leiorhachis*) are reported present in Kenya (Chikamai and Banks, 1993, Omondi *et al*., 2010) and may be the source of differentiation revealed in the present study. During sample collections, materials were collected from the whole species distribution range, possibly sampling all the three varieties. Inclusion of all the three varieties in this analysis might be the contributing factor for differentiation.

The distance based clustering analysis method revealed a strong structure among the 12 populations of *A. senegal*. Individuals were grouped into three groups reflecting the three putative varieties (*kerensis*, *senegal* and *leiorhachis*) with several overlap between *kerensis* and *senegal*. Such findings have been reported in the taxonomic study of *A. senegal* in Uganda using morphological characters (Mulumba and Kakudidi, 2009). Field observations have also been made in Kenya where variety *senegal* and *kerensis* show morphological overlaps unlike the distinct *leiorhachis* (Omondi *et al*., unpublished data). The results agree with initial taxonomic work that separated the species into different varieties (Brenan, 1983). This finding lends support to the concept of keeping the varieties separate in utilization (Chikamai and Banks, 1993). Since the species has generated a lot of interest based on its potential for quality commercial gum arabic production in Kenya, there is need for caution to treat the varieties differently. Biochemical studies of Kenyan gum arabic have established quality variations and this could be attributed to the mixing of gum from the different varieties.

Ecological and geographic differentiations are important factors, which influence breeding and sampling strategies of tree crops. In the test of hypothesis of isolation by distance, results of this study found positive but non-significant correlation between genetic and geographic distances. Populations that are located far apart were found to be clustered together while those closely located separated. This is an indication of efficient gene flow among the populations. The overall pattern of genetic divergence among the populations studied reflects a story of short-term separation and consistent gene flow. The populations thus share gene pool, and there is no evidence of any barriers likely to restrict gene flow between them.

Conclusion

To improve on the quality of gum arabic production and good market returns, gum collections should be done and separated based on variety. Through this, livelihoods of the local populations that entirely depend on the resource will be enhanced. From conservation point of view and since varieties clustered separately, each variety should be conserved separately. A representative sample of natural populations of each variety could then be used to develop *in situ* or *ex situ* conservation strategy of the species. Findings could help define a strategy for elaborate breeding population. To start an improvement programme, the breeding population should consist of many individual trees selected within few populations of the varieties to capture larger proportion of the variation.

Acknowledgements

This study was funded by Kenya Forestry Research Institute (KEFRI) and ACACIAGUM project. KEFRI Biotechnology staff are acknowledged for their support during the study.

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Anthropogenic Influences on Species Composition, Richness and Diversity in Museve and Mutuluni Dryland Forest Fragments, Kitui; Kenya

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Abstract

Pressure from increasing human population threatens existence of many dryland forest fragments such as Museve and Mutuluni fragments. Besides, limited documentation on trees species composition and associated impacts from human activities is available for bench marking, managerial and policy interventions. Thus, objectives of this paper are; (i) document key human activities in Museve and Mutuluni dryland forest fragments, (ii) capture their tree species composition and; (iii) comparatively assess how human activities have impacted their tree species composition, richness and diversity. Two belt transect of 20 m wide and 500 m long that employed use of nested sample plots of 20 m by 20 m, sub plots of 10 m by 10 m and micro plots of 2 m by 5 m were established in each forest. Data on human activities and mature trees was taken from the main plots while that of saplings and seedlings in the sub plots and micro plots respectively. Information gathered included; tree species identification, diameter measurements and evidence of human activities. Species richness, Jaccard coefficient index and Shannon-Weiner diversity index were computed and used to compare species richness, similarity and diversity respectively. Mann-Whitney, z-test, t-test and logistic regression were used for data analysis. Human activities occurred in both forests but with higher frequency ($P<0.05$) in Museve. Introduction of exotic species boosted species composition, altered dominances in Museve and reduced species similarity across the two forests. Tree cutting reduced ($P<0.05$) species richness and diversity in Museve. Thus, human activities affected species composition in both forests. The study recommends improved conservation measures and further research on consequences of altering species dominance by *Eucalyptus saligna* in Museve forest.

Keywords: Human activity, species composition, diversity, dominance, richness, fragments

Introduction

Forest ecosystems provide key regulative, provisional, cultural and supportive ecosystem services essential for conservation of the earth's biodiversity and human wellbeing (MEA, 2005). However, these ecosystems require sound conservation measures for adequate functioning and productivity which is highly anchored on integrity of their species composition, richness and diversity (FAO, 2010; Mutiso, *et al.*, 2015).

Destructive human activities such as deforestation, over grazing, over-exploitation, introduction of invasive species, pollution and climate change have significantly impacted tree species composition, richness and diversity in global forest ecosystems especially within the tropics (Mahbud, 2008; Morris, 2010; Obiri, 2011). Studies by Gonzalez (2001) and MEA (2005) have indicated that the earth's biodiversity is on record decline in human history from human influences with no indication of slowing down. As a result, more fragile ecosystems, unsustainable livelihoods and flimsy local and national economies are the manifest and the drylands worst affected (Mathu, 2011; Middleton and Thomas, 1997; Ochola *et. al*., 2010).

Arid and Semi-Arid Lands (ASALs) are all times fragile and more vulnerable ecosystems to degradation (FAO, 2010; KFS, 2012). Consequently, uncontrolled human activities has resulted into widespread fragmentation of forest cover (Kigomo, 2003). Today, much of forest cover in drylands is concentrated around hilltops and/or conservation reserves, where they provide much needed ecosystem services in these areas (UNEP, 2007).These hilltops form key water catchment areas, hold unique life forms and are important habitats essential to the long-term maintenance of biodiversity and other natural processes in the drylands (Gachathi, 2012).

Nevertheless, not much is known about tree species composition, richness and diversity of these dryland forests fragments (Gachathi, 2012). Consequently, many forest fragments in drylands like Museve and Mutuluni forests are under threat from human activities by the surrounding human population. Extent and severity of human influences in these hilltop forest fragments are not known, a case that requires immediate attention. The lack of information on how human activities impact on sustainable use of forestry resources in hill top forests hinder sustainable use of these resources.

The objectives of this study was to examine frequencies of human activities in Museve and Mutuluni dryland forest fragments; and to comparatively investigate the effects of human activities on tree species composition, richness and diversity within and between Museve and Mutuluni dryland forest fragments to provide firm scientific knowledge required in guiding the local community, managers and policy makers in effective and sustainable conservation of the forests.

Materials and Methods

Study area

The study was undertaken at Museve and Mutuluni forest fragments (Figure 1). Museve forest fragment (48 ha) and Mutuluni forest fragment (596 ha) are located in Kitui Central (667 km^2) and Kitui East Constituencies (5,119.7 km^2) respectively; Kitui County (KNBS, 2010; MENR, 2002). The area receives an annual average rainfall ranging from 750 mm to 1150 mm distributed in two rainy seasons. Temperatures ranges from a minimum of 15.7°C to a maximum of 27.1°C annually while the geology mainly consists of sedimentary plains which are usually low in natural fertility (MENR, 1994; MoA, 1983). Both forest fragments are state owned secondary forests previously owned by local communities who were evicted by colonial government in early 1900's (Mbuvi *et al.,* 2010). Since then, Mutuluni forest has been left to recover naturally while Museve forest has undergone several human interventions including introduction of exotic tree species by forest management which failed due to ecological conditions (Mbuvi *et al.,* 2010). As a result several remnant exotic species are present integrated with natural regeneration.

Sampling design and data collection techniques

Belt transects of 500 m long by 20 m wide that employed use of nested sampling plots was the main study design. Two belt transects i.e. transect 1 and transect 2 were longitudinally established in each forest. The highest elevation guided the choice of start point for transect 1 which run on one direction. To separate the two transects, a distance of 50 m from the start point on the opposite direction was marked as the start point for transect 2 which run on the opposite direction. In each transect, main plots measuring 20 m by 20 m were established which were further subdivided into subplots measuring 10 m by 10 m and microplots measuring 2 m by 5 m.

In the main plots, data on evidences of human activities and on mature trees were collected.Evidences of the predetermined indicators of human activities were; signs of charcoal burning, pit sawing, footpaths, grazing, fire, debarking, grass cutting, tree cutting and presence of exotic trees.Plant growth characteristics were used to identify and to distinguish trees from other forms of vegetation. A maximum height of 5 m at maturity criteria was used to distinguish trees from shrubs. The trees were identified and diameter measurements at breast height (dbh) for mature trees (≥5cm dbh) collected. In the subplots, data on saplings (trees 1cm ≥ dbh < 5cm) was collected while in the microplots seedlings were identified and counted.

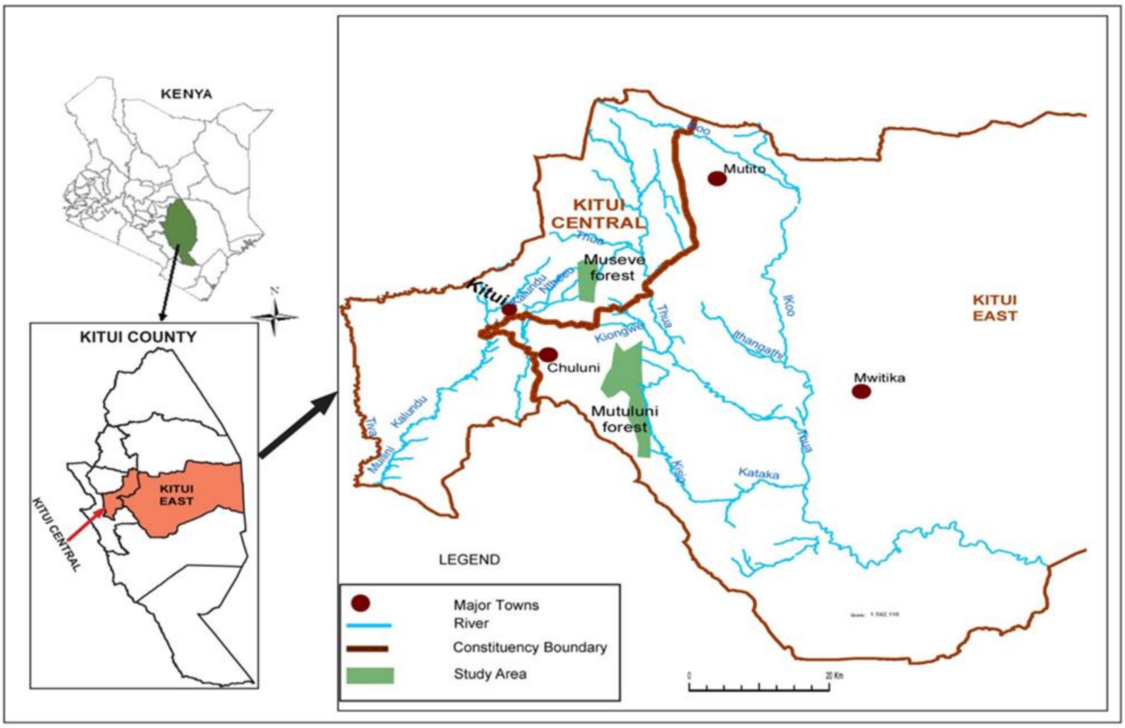

Figure 1. Museve and Mutuluni forest fragments in Kitui County; Kenya.

Methods of data analysis

Incidences of human activities were summarized into a frequency table indicating number of plots in which the incidences occurred.A two-sided test of equality for column proportions using z-test was done. To assess intensity of tree cutting, the number of trees cut per plot was converted into stems per hectare (Equation 1); explored for deviation from normality and compared within and between the two forests using student t-test and Mann-Whithey test statistics at 5% level of significance.

Stems/ha = Number of trees/Area(Ha) (1)

All trees; seedlings, saplings and mature individuals in both forests were listed and identified by their families, genus and species to capture the forests' composition. Botanical guides such as Useful Trees and Shrubs of Kenya (Maundu and Bo Tengnas, 2005) and The Kenya Trees, Shrubs and Lianas (Beentje, 1994)were used for species identification. Further identification by aid of taxonomist was also done at Kenya Forestry Research Institute (KEFRI) Kitui and Muguga Centres. The Jaccard similarity coefficient (Kentand Corker, 1992) and Species Importance values (SIV) as cited by Kacholi (2014) were calculated (Equations 2 and 3 respectively) to examine species similarity and species ecological importance respectively between the two forests. Calculated SIV were ranked from the largest to the smallest in each forest for assessment and the most ten important species identified.

Jaccard's index (JI_A) = a / (a+b+c) (2)

Where,

a - Number of species common in Museve and Mutuluni forests

b - Number of species in Museve but not Mutuluni forest

c - Number of species in Mutuluni but not Museve forest

SIV = Rf + RDe + RDo (3)

Where,

Rf – Species Relative Frequency

RDe – Species Relative Density

RDo – Species Relative Dominance

Tree species diversity indices were computed (Equation 4) for each 20 m by 20 m plot using Shannon-Weiner diversity index (Harris, 1983). The Shannon-Weiner's index was most preferred because it provides an account of both the abundance and evenness and does not unreasonably favour one species (Omoro, 2012).

$$\mathbf{H'} = -\sum_{i=1}^{R} pi\ lnpi \quad (4)$$

Where;

H' -Shannon Diversity Index,

pi- Proportion of individuals of species belonging to the ith species in the data set of interest

The derived Shannon's diversity indices were further converted into effective numbers (Equation 5) to compare trees species diversity within and between the two forests. According to Lou (2006) effective number of species is the true diversity of the community in question and is simply the number of equally-common species required to give a particular value of an index;

$$Effectives\ Numbers = Exp(H') \quad (5)$$

Where*H'* -Shannon Diversity Index,

Species richness (S) was also done at every 20m by 20m plot by counting the number of species present. The following equation (Equation 6) as cited by Omoro(2012) was applied.

$$Species\ Richness\ (S) = \sum n \quad (6)$$

Where *n* is number of species in a plot.

Student t-test was used to compare tree species richness (*S*) and tree species diversity indices (*H'*) within and between Museve and Mutuluni forests. Logistic regression was used to investigate the impacts of documented human activities in each forest. The human activities were regressed as independent predictor variables against the dependent variables tree species richness (S) and species diversity (*H'*) respectively. The model statistics and coefficients statistics were given in a summary table.

Results

Types and prevalence of human activities in Museve and Mutuluni forest reserves

Only five indicators of human activities were recorded in both Museve and Mutuluni forests. These were: presence of foot paths, grazing, debarking of trees, tree cutting and introduction of exotic species. Three of the indicators occurred in both forest while debarking and presence of exotic species occurred only in Mutuluni and Museve forest respectively (Table 1). A two-sided test of equality for column proportions using z-test indicated significant ($P < 0.05$) differences in frequencies of presence of tree cutting, grazing and foot paths. The frequencies were higher in Museve forest compared to Mutuluni. Presence of exotic species and human and/or livestock tree debarking were not compared because they only occurred in either Museve or Mutuluni forest (Table 1).The number of trees cut was also significantly ($P < 0.05$) higher in Museve forest. Moreover, within Museve forest the number of trees cut varied significantly ($P < 0.05$) whereas no significant ($P > 0.05$) difference was observed within Mutuluni forest.

Table 1. Types and frequencies of human activities recorded in Museve and Mutuluni dryland hilltop forest reserves

Human activities			Forest: Museve forest	Forest: Mutuluni forest
		Count	Count	Count
Tree Cutting	0	$0^{1,2}$	3_a	23_b
	1	$0^{1,2}$	47_a	27_b
Grazing	0	$0^{1,2}$	18_a	40_b
	1	$0^{1,2}$	32_a	10_b
Human/livestock	0	$0^{1,2}$	50^2	44_a
debarking	1	$0^{1,2}$	0^2	6_a
Footpaths	0	$0^{1,2}$	20_a	38_b
	1	$0^{1,2}$	30_a	12_b
Exotic species	0	$0^{1,2}$	3_a	50^2
	1	$0^{1,2}$	47_a	0^2

Note: Values in the same row and subtable not sharing the same subscript are significantly different at p< .05 in the two-sided test of equality for column proportions. Cells with no subscript are not included in the test. Tests assume equal variances.

Tree species composition and species diversity

Tree species composition

A total of 68 tree species (seedlings, saplings and mature trees) belonging to 28 families were recorded in Museve forest (Table2) while 57 tree species belonging to 31 families were recorded in Mutuluni forest (Table 3). However, the number of tree species formature trees recorded in Mutuluni forest (52)was higher than that of Museve (48). In addition, Museve forest recorded more seedlings and saplings (regeneration composition) compared toMutuluni (Table 3). This may imply that Museve is recovering from disturbances.

Table 2. List of tree species in Museve Forest Reserve, Kitui county

	Family Name	*Species Name*	*Mature Trees*	*Saplings*	*Seedlings*
1	Mimosaceae	*Acacia hockii* De Wild.	√	√	√
2	Mimosaceae	*Acacia nilotica* L.	√	√	√
3	Mimosaceae	*Acacia polyacantha* Willd.	√	√	√
4	Mimosaceae	*Acacia Senegal* (L.) Willd.			√
5	Mimosaceae	*Acacia seyal* Delile.	√	√	√
6	Apocynaceae	*Acokanthera oppositifolia* (Lamarck) Codd.	√	√	√
7	Fabaceae	*Acrocarpus fraxinifolius* Arnold.		√	√
8	Mimosaceae	*Albizia anthelmintica* (L.) Benth.			√
9	Annonaceae	*Annona senegalensis* Pers.			√
10	Euphorbiaceae	*Antidesma venosum* Tul.	√	√	√
11	Malvaceae	*Azanza garckeana* F. Hoffm.	√	√	√
12	Euphorbiaceae	*Bridelia taitensis* Vatke & Pax ex Pax.	√	√	√
13	Rutaceae	*Calodendrum capense* (L.f.) Thunb.	√	√	
14	Apocynaceae	*Carissa spinarum* L.		√	√
15	Caesalpiniaceae	*Cassia abbreviate* Oliv.	√		
16	Combretaceae	*Combretum collinum* Fres.	√	√	√
17	Combretaceae	*Combretum molle* G.	√	√	√
18	Combretaceae	*Commelina benghalensis* L.		√	
19	Burseraceae	*Commiphora Africana*(A. Rich.) Engl.	√	√	√
20	Burseraceae	*Commiphora habesinica* Engl.		√	√
21	Euphorbiaceae	*Croton megalocarpus* Hutch.	√	√	√
22	Cupressaceae	*Cupressus lusitanica* Mill.	√	√	√
23	Papilionaceae	*Dalbergia melanoxylon* Guill. & Perr.	√	√	√
24	Mimosaceae	*Dichrostachys cinerea* (L.) Wight & Arn.	√	√	√
25	Ebenaceae	*Diospyros mespiliformis* Hochst. ex A.DC.	√	√	√
26	Papilionaceae	*Erythrina abyssinica* Dc.	√	√	
27	Myrtaceae	*Eucalyptus grandis* W. Hill.	√		
28	Myrtaceae	*Eucalyptus paniculata* Sm.	√	√	
29	Myrtaceae	*Eucalyptus saligna* Sm.	√	√	√
30	Ebenaceae	*Euclea divinorum* Hiern.	√	√	√
31	Euphorbiaceae	*Euphorbia candelabrum* Trémaux ex Kotschy.	√		√
32	Rutaceae	*Fagara chelybeum* Engl.		√	√
33	Moraceae	*Ficus sycomorus* L.		√	
34	Moraceae	*Ficus thonningii* Blume.			√
35	Tiliaceae	*Grewia bicolor* Juss.	√	√	√
36	Proteaceae	*Grevillea robusta* A.Cunn. ex R.Br.	√	√	√
37	Umbelliferae	*Heteromorpha trifoliata (*H.L.Wendl.) Eckl. & Zeyh.		√	
38	Anacardiaceae	*Lannea schimperi* (Hochst. ex A.Rich.) Engl.			√
39	Anacardiaceae	*Lannea schweinfurthii* Engl.	√		
40	Anacardiaceae	*Lannea triphylla* (Hochst. ex A.Rich.) Engl.	√	√	
41	Capparaceae	*Maerua crassifolia* Forssk.	√	√	√

	Family Name	*Species Name*	*Mature Trees*	*Saplings*	*Seedlings*
42	Anacardiaceae	*Mangifera indica* L.		√	√
43	Bignoniaceae	*Markhamia lutea* (Benth.) K.Schum.			√
44	Celastraceae	*Mystroxylon aethiopicum (*Thunb.) Loes.		√	√
45	Ochnaceae	*Ochna holstii* Engl.			√
46	Ochnaceae	*Ochna ovata* F. Hoffm.	√	√	√
47	Papilionaceae	*Ormocarpum kirkii* S. Moore.	√	√	√
48	Papilionaceae	*Ormocarpum trachycarpum* (Taub.) Harms.	√	√	
49	Santalaceae	*Osyris lanceolata* Hochst. & Steud.	√	√	√
50	Rubiaceae	*Pavetta gardeniifolia* Hochst. ex A. Rich.	√	√	√
51	Caesalpiniaceae	*Piliostigma thonningii* Schum.		√	√
52	Salicaceae	*Populus ilicifoilia* Engl.	√	√	√
53	Myrtaceae	*Psidium guajava* L.	√	√	√
54	Anacardiaceae	*Rhus natalensis* Bernh. ex C.Krauss.	√	√	√
55	Anacardiaceae	*Rhus vulgaris* Meikle.	√	√	√
56	Anacardiaceae	*Sclerocarya birrea* A.Rich.	√	√	
57	Caesalpiniaceae	*Senna siamea* Lam.	√	√	√
58	Caesalpiniaceae	*Senna singueana* Delile.	√	√	√
59	Caesalpiniaceae	*Senna spectabilis* (DC.) H.S.Irwin & Barneby.	√	√	√
60	Apiaceae	*Steganotaenia araliacea* Hochst.	√	√	√
61	Loganiaceae	*Strychnos decussata* Pappe.		√	√
62	Loganiaceae	*Strychnos spinosa* Lam.	√	√	
63	Euphorbiaceae	*Synadenium compactum* Var. rubrum S.Carter.	√	√	
64	Combretaceae	*Tamarindus indica* L.			√
65	Combretaceae	*Terminalia brownii* Fres.	√	√	√
66	Combretaceae	*Terminalia spinosa* Engl.	√	√	√
67	Rubiaceae	*Vangueria madagascariensis* J.F.Gmel.		√	
68	Verbenaceae	*Vitex payos* (Lour.) Merr.	√	√	√
	Total		**48**	**55**	**54**

√ Indicates presence of the species at either maturity, sapling and/or seedling stage**.**

Table 3. List of tree speciesin Mutuluni Forest Reserve, Kitui County

	Family Name	*Species Name*	*Mature Trees*	*Saplings*	*Seedlings*
1	Mimosaceae	*Acacia nilotica* L.	√		
2	Mimosaceae	*Acacia polyacantha* Willd.	√		
3	Mimosaceae	*Acacia seyal* Delile.	√		
4	Mimosaceae	*Albizia anthelmintica* (L.) Benth.	√		
5	Mimosaceae	*Albizia gummifera* Gmel.	√		
6	Malvaceae	*Azanza garckeana* F. Hoffm.	√	√	√
7	Melianthaceae	*Bersama abyssinica* Fresen.	√	√	√
8	Capparaceae	*Boscia angustifolia* A. Rich.		√	√
9	Euphorbiaceae	*Bridelia taitensis* Vatke & Pax ex Pax.	√	√	√
10	Rutaceae	*Calodendrum capense* (L.f.) Thunb.	√	√	√
11	Apocynaceae	*Carissa spinarum* L.	√	√	

	Family Name	Species Name	Mature Trees	Saplings	Seedlings
12	Rhizophoraceae	*Cassipourea celastroides* Alston.	√	√	
13	Combretaceae	*Combretum collinum* Fres.	√	√	√
14	Combretaceae	*Combretum molle* G.	√	√	√
15	Burseraceae	*Commiphora Africana* (A. Rich.) Engl.	√	√	√
16	Burseraceae	*Commiphora eminii* Engl.	√		√
17	Burseraceae	*Commiphora habesinica* Engl.	√	√	
18	Burseraceae	*Commiphora spp.*	√		
19	Boraginaceae	*Cordia monoica* Roxb.	√	√	√
20	Euphorbiaceae	*Croton megalocarpus* Hutch.	√	√	√
21	Papilionaceae	*Dalbergia melanoxylon* Guill. & Perr.	√	√	√
22	Mimosaceae	*Dichrostachys cinerea* (L.) Wight & Arn.	√	√	
23	Ebenaceae	*Diospyros mespiliformis* Hochst. ex A.DC.	√	√	√
24	Salvadoraceae	*Dobera glabra* (Forssk.) Juss. ex Poir.	√		
25	Sterculiaceae	*Dombeya burgessiae* Gerrard ex Harv.	√	√	√
26	Ebenaceae	*Euclea divinorum* Hiern.	√	√	√
27	Euphorbiaceae	*Euphorbia tirucalli* L.		√	√
28	Moraceae	*Ficus glumosa* Del.	√		√
29	Moraceae	*Ficus thonningii* Blume.	√	√	√
30	Flacourtiaceae	*Flacourtia indica* (Burm. f.) Merr.	√	√	
31	Tiliaceae	*Grewia bicolor* Juss.	√	√	√
32	Rutaceae	*Harrisonia abyssinica* Oliv.	√	√	
33	Anacardiaceae	*Lannea schweinfurthii* Engl.	√	√	√
34	Anacardiaceae	*Lannea triphylla* (Hochst. ex A.Rich.) Engl.	√	√	√
35	Fabaceae	*Lonchocarpus eriocalyx* Harms.	√	√	√
36	Celastraceae	*Maytenus obscura* (A. Rich.) Cufod.	√	√	√
37	Celastraceae	*Mystroxylon aethiopicum (*Thunb.) Loes.	√	√	
38	Ochnaceae	*Ochna ovata F. Hoffm.*	√	√	√
39	Papilionaceae	*Ormocarpum kirkii* S. Moore.	√	√	
40	Santalaceae	*Osyris lanceolata* Hochst. & Steud.			√
41	Sapindaceae	*Pappea Capensis* Eckl. & Zeyh.	√	√	
42	Rubiaceae	*Pavetta gardeniifolia* Hochst. ex A.Rich.	√	√	√
43	Salicaceae	*Populus ilicifoilia* Engl.	√	√	√
44	Anacardiaceae	*Rhus natalensis* Bernh. ex C.Krauss.	√	√	
45	Anacardiaceae	*Rhus vulgaris* Meikle.	√	√	√
46	Anacardiaceae	*Sclerocarya birrea* A.Rich.	√		
47	Apiaceae	*Steganotaenia araliacea* Hochst.	√	√	
48	Loganiaceae	*Strychnos henningsii* Gilg.	√	√	√
49	Loganiaceae	*Strychnos madagascariensis* Poir.			√
51	Caesalpiniaceae	*Tamarindus indica* L.	√		
52	Rutaceae	*Teclea nobilis* Delile.	√	√	√
53	Combretaceae	*Terminalia brownii* Fres.	√	√	√

	Family Name	Species Name	Mature Trees	Saplings	Seedlings
54	Combretaceae	*Terminalia spinosa* Engl.		√	
55	Rubiaceae	*Vangueria madagascariensis* J.F.Gmel.	√	√	√
56	Rutaceae	*Zanthoxylum chalybeum* Engl.	√		
57	Rhamnaceae	*Ziziphus abyssinica*Hochst. ex A.Rich.	√	√	√
	Total		**52**	**43**	**31**

√ Indicates presence of the species at either maturity, sapling and/or seedling stage.

Species similarities and dominance

A. Species similarities

The computed Jaccard similarity coefficient (JI_A) between Museve and Mutuluni forest was 0.37. According to Marimon and Felfili (1997) this is below the critical value (JI_A = 0.5) indicating that tree species composition in Museve and Mutuluni forest were not similar. Likewise, tree species composition within Mutuluni forest reserve, with JI_A of 0.48, was not similar. However, within Museve forest, the JI_A was 0.67, meaning that the tree species composition within the forest were very similar.

B. Species dominance and importance values

The ten most dominant tree species in Museve forest included: *Eucalyptus saligna* Sm, *Azanza garckeana* F. Hoffm., *Combretum molle* G., *Euclea divinorum* Hiern. *Antidesma venosum* Tul. *Dichrostachys cinerea* (L.) Wight & Arn., *Erythrina abyssinica* Dc, *Commiphora africana* (A. Rich.) Engl., *Terminalia brownii* Fres. and *Calodendrum capense* (L.f.) Thunb. (Table 4) representing species important value of 53.51%. In Mutuluni forest, the ten most dominant species were: *Teclea nobilis* Delile, *Bersama abyssinica*Fresen., *Croton megalocarpus* Hutch., *Grewia bicolor*Juss, *Dombeya burgessiae* Gerrard ex Harv., *Terminalia brownii* Fres., *Diospyros mespiliformis* Hochst. ex A. DC., *Brideliataitensis* Vatke & Pax ex Pax., *Combretum collinum* Fres. and *Euclea divinorum* Hiern. (Table 4) representing a species important value of 58.58 %. Therefore, in both forests the ten most dominant species, which were less than 20 % of all recorded species n each forest, exhibited a dominance value greater than 50 %.

Table 4. Summary of the ten most dominant species in Museve and Mutuluni forests

	Museve forest		Mutuluni forest	
No.	**Species name**	**SIV %**	**Species name**	**SIV %**
1	*Eucalyptus saligna*Sm.	16.77	*Tecleanobilis*Delile	9.88
2	*Azanza garckeana*F. Hoffm.	7.31	*Bersama abyssinica*Fresen.	8.90
3	*Combretummolle*G.	5.28	*Croton megalocarpus*Hutch.	6.42
4	*Eucleadivinorum*Hiern.	4.93	*Grewiabicolor*Juss.	6.02
5	*Antidesmavenosum*Tul.	4.18	*Dombeyaburgessiae*Gerrard ex Harv.	5.95
6	*Dichrostachyscinerea*(L.) Wight & Arn.	3.91	*Terminalia brownii*Fres.	4.76
7	*Erythrinaabyssinica*Dc.	3.25	*Diospyrosmespiliformis*Hochst . ex A.DC.	4.70
8	*Commiphora Africana*(A. Rich.) Engl.	3.12	*Brideliataitensis* Vatke & Pax ex Pax.	4.56
9	*Terminalia brownii* Fres.	2.41	*Combretumcollinum*Fres.	3.71
10	*Calodendrumcapense*(L.f.) Thunb.	2.35	*Eucleadivinorum* Hiern.	3.68
Total		**53.51**		**58.58**

Species richness and diversity

The calculated mean diversity index for Mutuluni forest was 1.50 while Museve forest was 1.46 equivalent to effective number of species 4.5 and 4.3 for Mutuluni and Museve respectively. A normality test indicated that diversity indices in the 20m by 20m plots for both Museve and Mutuluni forest deviated from normal distribution (D (50) = 0.36 P< .05) in Museve and (D (50) = 0.32 P< .05) in Mutuluni forest respectively. Further, Mann-Whitney statistics revealed there were no significant differences (P> 0.05) in tree species diversity across the two forest reserves but it varied (P< 0.05) within each forest. Tree species richness in Museve forest were normally distributed (D (50) = 0.12 P> .05) whereas in Mutuluni they deviated (D (50) = 0.15 P< .05) significantly from normal distribution. Mann-Whitney test revealed there was not significant (P> 0.05) difference in species richness between the two forests but it varied within Mutuluni. However, within Museve forest species richness did not vary (t = 1.80, P> 0.05) significantly.

Impacts of human activities on tree species richness and diversity in Museve and Mutuluni forest reserves

When tree cutting, presence of grazing, foot paths, tree debarking and exotic species was regressed against species richness and diversity, the likelihood chi square statistics for logistic regression for species richness ($\chi2$ = 5.75, df = 4, P> 0.05) and diversity ($\chi2$ = 5.92, df = 4 P> 0.05) in Mutuluni forest were not significant. However, in Museve forest species richness ($\chi2$ = 29.77, df = 4, P< 0.05) and species diversity ($\chi2$ = 30.20, df = 4, P< 0.05) revealed significant differences. Thus human activities documented in Museve influenced species richness and diversity while in Mutuluni they did not have significant influence.

Test of parameters estimates indicated that only tree cutting significantly influenced tree species richness and diversity in Museve forest. Regression coefficients for tree cutting (*b* < -0.01, Wald $\chi 2$ = 30.00, *P*> 0.05) on diversity and (*b* < -0.01, Wald $\chi 2$ = 26.95, *P*> 0.05) on species richness were significantly different from zero (Table 5). Thus, tree cutting reduced species richness and diversity in Museve forest. Wald $\chi 2$ statistics for grazing, footpaths and introduction of exotic species were not significant (*P* > 0.05) implying that their occurrences did not have significant impacts on species richness and diversity in Museve forest (Table 5).

Table: 5. Test of parameter estimates for species richness and diversity in Museve forest

Dependent Variable	Parameter	B	Hypothesis Test		
			Wald Chi-Square	df	Sig.
Diversity	(Intercept)	0.98	53.09	1	0.00
	Grazing	-0.02	0.05	1	0.82
	Footpaths	-0.09	0.66	1	0.42
	Trees cut/ha	-0.004	30.00	1	0.00
	No. Exotic species/ha	<0.00	2.60	1	0.11
Richness	(Intercept)	2.34	267.86	1	0.00
	Grazing	0.02	0.03	1	0.87
	Footpaths	-0.10	0.69	1	0.41
	Treescut/ha	<-0.01	26.95	1	0.00
	No. Exotic species/ha	<0.00	0.24	1	0.62

Discussion

Presence of human activities were evident in both Museve and Mutuluni forest fragments. However, the frequencies and intensity of human activities was high in Museve forest compared to Mutuluni forest. Atwo-sided z-test for equality of column proportions revealed significant differences in presence of foot paths, cutting of trees and grazing between the two forests. The findings can be explained by the facts that Museve forest is near Kitui town and has high surrounding human population. compared to Mutuluni(KNBS, 2010). The nearby peopleare likely to exert more human influence. Mbuvi *et al.* (2010) noted that much of the fuelwood for cooking and brick kilning in the area were derived from the surrounding forest reserves.

Of the five anthropogenic activities recorded in Museve and Mutuluni forest, only introduction of exotic species and tree cutting which affected tree species composition, richness and diversity significantly.Introduction of exotic species in Museve forest resulted to high species richness and composition (68 species) in the forest compared to that of Mutuluni forest (57 species). Museve forest has experienced reafforestation programmes that targeted deliberate introduction of species not indigenous to the forest which are likely to enhance species composition (Mbuvi *et al*., 2010). It was observed that, all the eight remnant exotic species recorded in Museve forest were absent in Mutuluni forest.According to Sovu (2011), tree species introduction in areas where they were completely lacking enhances species composition and richness of the receiving ecosystems.

The remnant exotic tree species were present in all development stages (seedlings, saplings and mature trees) indicating that they have integrated very well with the natural regeneration. Similar findings were reported where such integrations enhanced tree species composition in Taita Hills (Omoro *et al.*, 2010). Also, presence of footpaths and grazing was higher in Museve forest compared to Mutuluni forest which may have resulted into higher edge effects. Omoro (2012) and Mutiso *et al.* (2015) noted that people and livestock movement in a forest may facilitated movement of plant propagules from the surrounding farmlands into the forest, thereby increasing species richness and composition, consequently, enriching tree species richness in Museve forest. This was vindicated by documentation of some fruit trees (*Psidium guajava* L. and *Mangifera indica L.*) in Museve forest which are usually domestic fruit trees in the study area (Table 2). Moreover, the regeneration (seedlings and saplings) composition for Museve forest was higher compared to mature trees compared to Mutuluni. This may be due to increased edge effects in Museve forest.

Results indicated that tree cutting significantly reduced tree species richness and diversity in Museve forest while no significant impacts were evident in Mutuluni. This is attributed to high intensity of tree cutting exhibited in Museve forest compared to Mutuluni. As a result, calculated Shannon-Wiener species diversity index for Museve forest (1.46) was lower compared to that of Mutuluni forest (1.50). Studies, Hitimana (2000) and Omeja *et al.* (2004) report that continued selective cutting of socio-economic tree species affect their regeneration and consequently species richness and diversity of a forest ecosystem. This is also in line with the findings that tree cutting particularly for fuelwood in ASALs is a major driver to to land cover change and degradationin drylands (Kiruki *et al.*, 2016; Kigomo, 2003).

Human activities influenced species dominances in the two forest fragments. The 10 most dominant tree species varied across the two forests despite sharing similar ecological conditions. As a result of species introduction, *Eucalyptus saligna* Sm. a remnant exotic species was the most dominant (SIV=16.77%)in Museve forest.It is worth noting that Eucalyptus spp have high coppicing ability, exhibit rapid biomass input and are known to exudate allelopathic chemicals that may inhibit undergrowth (KFS, 2009). Thus they are able to maintain their presence and dominance in the forest. The findings are also supported by Mutiso *et al*. (2013) and Obiri (2011) who shares that alien species may outcompete and substantially alter the gene pool of local plant materials thereby establishing their dominance and consequently influencing ecosystem functioning. The most dominant species are critical because they are known to influence ecosystem functioning most (Hitimana, 2000).Therefore, dominance of an exotic species in Museve forest is likely to interfere with the ecosystem functioning. Worse even, there is an increasing concern on the effect of *Eucalyptus spp* on the hydrological cycle and biodiversity conservation (KFS, 2009). On the contrary, Mutuluni forest did not have exotic tree species. As a result an indigenous species; *Teclea nobilis* Delile was the most dominant (SIV=9.88%) in the forest.

The widespread tree cutting recorded in both forests may have resulted into low calculated SIV of most species in both forests. Based on the SIV values, few (10) species represented high proportion (>50%) dominance in each forest (SIV >50%). Though, this is common with most tropical forest, it is an indication that most trees species were rare rather than common, hence the risk of local species extinction (Kacholi, 2014;Njunge and Mugo, 2011). There is therefore an urgent need for increased conservation efforts in both forests. Kacholi (2014) and Omeja *et al.* (2004) opinions that, over utilization of rare species or those species with social-economic value can result to their local extinction.

Human activities also influenced species composition across the two forests. The two forests share same ecological zone and experience similar climatic conditions, thus it would be expected that tree species composition across the two forests would be similar. This was not the case as the two forests exhibited low species similarities. This can be explained by exotic species in Museve forest resulting to different species composition from that of Mutuluni. Also, Museve forest documented high frequencies of human activities like grazing and footpaths that may increase the likelihood of introducing propagules of other tree species from the surrounding farmlands into the forest (Omoro, 2012; Mutiso *et al.,* 2013). This could have led to reducing similarity of species composition across the two forests. Besides, selective tree cutting is known to affect tree species composition (Kacholi, 2014; Hitimana *et al*., 2004).Thus, widespread selective tree cutting in both forests and may have resulted into unequal influences on species similarities across the two forests

It is also worth noting that low species similarity across the two forests implies that, each forest has certain tree species unique from each other (Kacholi, 2014). Hence, the need to conserve and protect each forest to minimise risks of local species extinction posed by threats from documented human activities. The high species similarity Index (JI_A = 0.67) within Museve forest may imply that similar tree species have been introduced throughout the forest. On the other hand similarity Index (JI_A = 0.48) for Mutuluni indicated low similarity in species composition. Hitimana (2000) and Mutiso *et al*. (2015) have also shown low species similarity within the same forest as it was the case for Mutuluni forest.

Conclusion and Recommendations

Only five out of the nine predetermined human activities were documented in Museve and Mutuluni forest reserves with high occurrences in Museve. Tree cutting and introduction of exotic tree species impacted tree species richness, diversity and composition the most. Presence of grazing, foot paths and tree debarking did not necessarily result into significant impacts.

Introduction of exotic species in Museve forest reserve increased species richness in Museve but resulted to low similarity in species composition across the two forests. Species dominances were also affected in Museve forest since *Eucalyptus salig*naan exotic species was the most dominant in the forest. Cutting of trees reduced species richness and diversity in Museve but no significant effects were documented in Mutuluni forest.

The study concludes that human activities affected tree species composition, richness and diversity for the two forests and Museve forest is more disturbed. Hence, there is need for proper management plans, heightened protection and monitoring of human activities in both forests with specific attention to Museve. Although grazing, foot paths and tree debarking did not reveal significant impacts in this research, it is worth considering them when designing conservation strategies for the two forests since they have been reported to affect species composition, richness and diversity directly or indirectly through creation of forest edge effects. Further research is recommended to understand the consequences of *Eucalyptus spp.*in altering tree species composition and ecological processes within Museve forest.

Acknowledgements

Authors acknowledge the logistical and technical support extended to this work by the Kenya Forest Service (Kitui) and Kenya Forest Research Institute (Kitui and Muguga). We also acknowledge the input by field crew.

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Interactions Between Native Tree Species and Environmental Variables Along Forest Edge-Interior Gradient in Fragmented Forest Patches of Taita Hills, Kenya

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Abstract
Comparative investigations were undertaken in five forest fragments (Chawia, Fururu, Mbololo, Ngangao and Vuria) of varying sizes in Taita Hills, Kenya to examine the effects of forest edge on soil moisture, nitrogen, phosphorus, potassium, pH, electrical conductivity and organic carbon (hereafter referred to as environmental variables) along forest edge-interior gradient and relate them to tree species distribution and abundance. For each of the forest fragment, belt transects proportional to the forest area were established for data collection. Within each belt transect, plots of 10.0x10.0 m were systematically established and replicated three times in a stratum at an interval of between 10.0 and 50.0 m along forest edge-interior gradient depending on the size of the forest fragment for assessment of environmental variables and tree species distribution and abundance. Results showed significant edge effect on the distribution and abundance of dominant and adaptable tree species i.e. *Macaranga conglomerata*, *Albizia gummifera*, *Syzygium guineense*, *Xymalos monospora*, *Tabernaemontana stapfiana* and *Maesa lanceolata* (p=0.012). Edge effect was also noted among the following environmental variables; soil pH in Mbololo (p<0.001), Ngangao (p<0.001) and Vuria (p=0.042), electrical conductivity (p=0.048) and nitrogen (p=0.038) in Fururu and potassium in Mbololo (p=0.002) and Ngangao (p=0.035). The distance from the forest edge influenced the distribution and abundance of 36.7% and 36.4% of most abundant species and less abundant species respectively. The environmental variables-tree species relationships established in this study could be utilized in selecting native tree species for rehabilitation programs to restore the degraded sites within the forest fragments.

Keywords: Forest fragmentation; Edge effect; Environmental variables; Interactions; Taita Hills

Introduction
Forest fragmentation is among the greatest threats to biodiversity (Pardini *et al*. 2010; Laurance *et al.*, 2011; Magnago *et al.*, 2014; Magnago *et al.*, 2015), species interactions and ecosystem processes in tropical forests (Steffan-Dewenter *et al.*, 2007; Morris, 2010). Fragmentation of forests into small isolated patches increases susceptibility of forest

remnants to edge effects (Matlack, 1993). The microclimate at the forest edge differs from that of the forest interior in attributes such as incident light, humidity, ground and air temperature, wind shear, and wind turbulence that sharply elevate rate of tree mortality and damage and influences most of the biotic variables (Jose *et al.*, 1996; Laurance *et al.*, 1997; Laurance *et al.*, 2011). These physical changes affect biological processes such as litter decomposition and nutrient cycling, and the forest structure, composition of vegetation and ecological function along forest edges exposed to non-forested habitats (Bennett and Saunders, 2010).

Effects of increased forest edge alter species interactions by increasing the degree of interaction among edge and forest interior species (Laurance *et al.*, 1997; Laurance *et al.*, 2000; Laurance *et al.*, 2011). Tree species growing on the edge are usually those adapted to edge microclimates and are often pioneer species found in the early stages of forest succession in any given region (Kupfer and Malanson, 1993). The responses of forest interior species to conditions that develop along the newly created forest edge vary, some species are advantaged and increase in abundance (Bennett and Saunders, 2010) while others are unable to survive in the newly created conditions and hence decline, becoming locally extinct (Laurance, 2002; Bennett and Saunders, 2010).

Edge effects are among the most significant drivers of ecological change in small forest fragments (Laurence *et al.*, 2011) and are responsible for wide ranging changes in community composition of trees (Laurance *et al.*, 2000; Laurance et al., 2006a; Laurance *et al.*, 2006b) and lianas (Laurance *et al.*, 2001). Stresses related to edge effects reduce establishment of shade-tolerant species in fragmented forests leading to drastic changes in tree species richness and composition along forest edge-interior gradient (Benitez-Malvido and Martinez-Ramos, 2003; Laurance *et al.*, 2006a; Laurance *et al.*, 2006b; Laurance *et al.*, 2007; Laurance *et al.*, 2011). The distance to which different edge effects penetrate into fragments varies widely, ranging from 10 to 300 m (Jose *et al.*, 1996; Laurance *et al.*, 2002). The environmental conditions progressively change with distance from the forest edge (Matlack, 1993; Jose *et al.*, 1996; Marchand and Houle, 2006; Bergès *et al.*, 2013). Besides, the distribution and occurrence of woody and herbaceous plants in a forest community changes from the forest edge to the interior depending on edge type and aspect (Gehlhausen *et al.*, 2000; Honnay *et al.*, 2002; Marchand and Houle, 2006). Gehlhausen *et al*. (2000) demonstrated that species abundance was correlated to environmental variables such as canopy openness and soil moisture, two variables that often vary with distance from the forest edge (Cadenasso *et al.*, 1997; Laurance, 2007). Similarly, the differences in species composition from the forest edge to the forest interior have been attributed to the changes in soil nutrients (Aerts *et al.*, 2006; Laurance, 2007).

Spatial variability of soil physical and chemical properties has been reported along forest edge-interior gradient (Redding *et al.*, 2003; Toledo-Aceves and García-Oliva, 2007; Laurance, 2008; Bergès *et al.*, 2013). For example organic carbon, pH, total nitrogen, available phosphorus and soil moisture increases towards forest interior (Camargo and Kapos, 1995; Jose *et al.*, 1996; Aerts and Chapin, 2000; Laurance *et al.*, 2000). Thus, it is has been concluded that the soils on the forest edge have lower nutrient levels than those in forest interior (Toledo-Aceves and García-Oliva, 2007; Laurance, 2007; Laurance *et al.*, 2008; Bergès *et al.*, 2013). Variation of soil properties along forest edge-interior gradient affects floristic composition in a pattern that is correlated to edaphic variables (Jose *et al.*, 1996; Laurance *et al.*, 2006a; Laurance *et al.*, 2006b; Laurance *et al.*, 2007; Xu, 2008; 2011; Zhang *et al.*, 2013). For instance, *Trillium camschatcence* and *Trillium ovatum* are positively correlated to distance to the forest edge and negatively correlated with soil and air temperature, soil variables that vary with distance from forest edge (Jules, 1998; Tomimatsu and Ohara, 2003).

Whereas the results of several soil-vegetation relationships studies have clearly shown that spatial distribution and abundance of species in the forests is related to soil properties (Omoro *et al.*, 2011; Zhang *et al.*, 2013; Zhang *et al.*, 2016), the relationships between soil variables and tree species distribution and abundance along forest edge-interior gradient have not been comprehensively explored in fragmented Afromontane forests in tropical regions of Africa including Kenya. Taita Hills forest fragments provide exceptional sites to determine tree species that are best suited to particular sites with respect to the distance from the forest edge, and if this is related to specific soil variables. This is because the prevailing land uses in Taita Hills such as small-scale crop farming, mining and creation of new settlements have produced landscapes dominated by small (<300 ha) and irregularly shaped forest fragments (Pellikka *et al.*, 2009; Omoro *et al.*, 2010; Omoro *et al.*, 2011; Wekesa *et al.*, 2016). Such small and isolated forest fragments are highly vulnerable to the edge effects and deleterious consequences of forest fragmentation (Laurance *et al.*, 2002; Barlow *et al.*, 2006; Cochrane and Laurance, 2008), hence the choice of these sites for this study.

Although several studies on the dynamics of woody plant communities have been undertaken in fragmented forests of Taita Hills (Beentje, 1988; Pellikka et al., 2009; Omoro et al., 2010; Omoro *et al.*, 2011; Aerts *et al.*, 2011), only a single study has ever focused on the relationships between tree species and soil properties (Omoro *et al.*, 2011). However, Omoro *et al*. (2011) did not evaluate the ‘edge effects’ on soil physical and chemical properties along the gradient from the forest edge to the forest interior and how they are related to spatial distribution and abundance of tree species.

Knowledge about relationships between distribution and abundance of tree species and soil properties is crucial for planning successful forest landscape restoration programs. Therefore, the objective of this study was to determine how the forest edge affects soil physical and chemical properties along a gradient from the forest edge to the forest interior, and the implications on tree species distribution and abundance in fragmented forests of Taita Hills. The following hypotheses were tested: (i) soil physical and chemical properties are different on the forest edge, intermediate forest and forest interior, (ii) the distribution and abundance of tree species reflects the changes in soil physical and chemical properties along forest edge-interior gradient.

Materials and methods

Description of the study area

The study was undertaken in five forest fragments (Mbololo, Ngangao, Chawia, Fururu and Vuria) in Taita Hills (Figure 1). The approximate areas of the forest fragments studied are as follows; Mbololo (200.0 ha), Ngangao (120.0 ha), Chawia (86.0 ha), Fururu (5.0 ha) and Vuria (1.0 ha) (Beentje, 1988; Pellikka *et al.*, 2009). The forest fragments have similar physical environment, are less than 21 km apart, were once one continuous block, and hence had similar plant communities (Bytebier, 2001; Adriaensen *et al.*, 2006). The long rainy season occurs from March to May and a shorter rainy season in November-December, but the mist and cloud precipitation is a year-round phenomenon in the Hills. The average yearly rainfall is 2000 mm (Pellikka *et al.*, 2009; Republic of Kenya, 2009). The average temperature is 23ºC with variations between 18ºC and 24.6ºC (Republic of Kenya, 2013). The Hills experience lower temperatures of 18.2ºC compared to the lower zones which have an average temperature of 24.6ºC (Republic of Kenya, 2013). The average relative humidity is 79 and 83 % for the lower zones and the Hills respectively (Republic of Kenya, 2013).

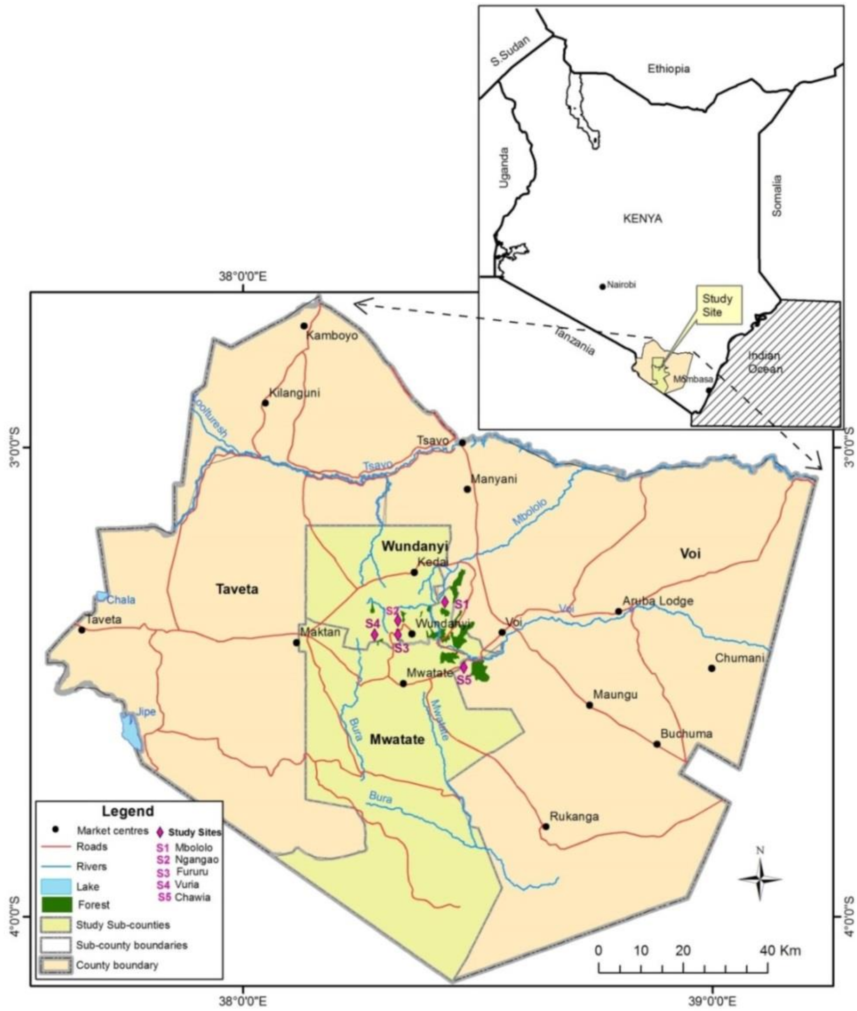

Figure 1. A map of Taita Taveta County showing the study sites

The soils are predominantly Cambisols originating from weathered gneiss and are often gravely to sandy-loamy and shallow (Sombroek *et al.*, 1982). The soils are well drained and moderately fertile. Majority of Cambisols are in a transitional stage of development from a young soil to a mature one (Sombroek *et al.*, 1982). On the steep slopes and transitional zones, the dominant soil types are regosols, which are shallow soils, have high permeability and low water holding capacity (Sombroek *et al.*, 1982). Due to the favourable climatic and edaphic conditions, the forested land in Taita Hills has been cleared for agriculture and remaining forests have been used for firewood collection, charcoal production and grazing (Pellikka *et al.*, 2009).

Sampling design

Belt transects and 10 m x 10 m plots were used for data collection along forest edge-interior. Forest edge was defined as the interface between forested ecosystems and farmlands. The size and number of belt transects varied among the forest fragments depending on the fragment size (Table 1). The number of plots also varied among the fragments depending on the size of the forest fragment. Mbololo had a total of 27 plots, Ngangao (15), Chawia (12), Fururu (9) and Vuria (9). Mbololo had 9 plots each on the forest edge, intermediate forest and forest interior, Ngangao (5), Chawia (4), Fururu (3) and Vuria (3). Transects were laid up slope from the edge of the forest to the forest interior.

Table 1: Sampling frame and intensity for the study. The size and the number of transects are proportional to the fragment size

Forest Fragment	Area (ha)	Transect Dimensions (m)		Number of Transects	Numbe r of plots
		Length	Width		
Mbololo	200.0	150.0	40.0	9	27
Ngangao	120.0	120.0	40.0	5	15
Chawia	86.0	90.0	40.0	4	12
Fururu	5.0	60.0	40.0	3	9
Vuria	1.0	30.0	40.0	3	9

Tree data collection

The assessment of tree species was undertaken in plots and sub-plots established within the belt transects. Within each belt transect, plots of 10 mx10 m were systematically established and replicated three times in a stratum at an interval of between 10.0 and 50.0 m along the forest edge-interior gradient depending on the size of the forest fragment. All the trees with diameter at breast height (DBH) greater than 2.5 m in the 10 m0 x 10 m plot were identified by their botanical names and recorded.

Data on the distribution and abundance of *Macaranga conglomerata*, *Albizia gummifera*, *Syzygium guineense*, *Xymalos monospora*, *Tabernaemontana stapfiana* and *Maesa lanceolata*, the six dominant and adaptable tree species (Omoro *et al.*, 2010; Aerts *et al.*, 2011) was also collected in all the plots. These species are indicator species sensitive to environmental changes and quickly respond to adverse ecosystem changes; hence the species are used as a diagnostic proxy for natural forest ecosystems health (Aerts *et al.*, 2011; Wekesa *et al.*, 2016).

Soil sampling

Three replicate of soil samples were randomly collected using soil auger at depths of 0-15 cm and 15-30 cm (Ojoyi *et al.*, 2014). The soil samples were composited to obtain a representative sample for the plot, packaged in zip lock bags and taken to the laboratory for analyses to determine the levels of moisture, nitrogen, phosphorus, potassium, pH, electrical conductivity (EC) and organic carbon. In total, 432 soil samples were collected from 72 plots spread across five forest fragments.

Soil analysis for physical and chemical properties

Prior to the analysis, the soil samples were air-dried and sieved using 2.0 mm sieve. Phosphorus and nitrogen were determined using Olsen and Kjeldahl methods respectively (Okalebo *et al*., 2002). Measurements of potassium involved extraction of soil samples using ammonia acetate pH 7 followed by spraying the contents into the flame photometer model Corning M 410 for potassium measurement (Okalebo *et al.*, 2002). Organic carbon was determined using Walkley-Black method through complete oxidation (Walkley and Black, 1934). Determination of soil pH and electrical conductivity (EC) involved the use of soil pH meter and electrical conductivity meter respectively as prescribed by Anderson and Ingram (1993) and Okalebo *et al.* (2002). Soil moisture content was determined using oven-dry method (Okalebo *et al.*, 2002).

Data analysis

One-way Analysis of Variance (ANOVA) and Tukey's post hoc test were used to test the presence or absence of significant effects in edaphic factors (moisture content, nitrogen, phosphorus, potassium, pH, EC and organic carbon) within and among the forest fragments along forest edge-interior gradient (forest edge, intermediate forest and forest interior) at 5% probability significance threshold.

Canonical Correspondence Analysis (CCA) was used to determine the relationships between tree species and edaphic factors as well as species association along the forest edge-interior gradient. To avoid rare tree species distorting the results, only tree species that occurred in at least 6% of the plots were included in the analysis. Tree species classification involved two categories: most abundant and less abundant. Most abundant tree species were those species that occurred in at least 11% of the sampled plots while less abundant tree species were those that occurred in at least 6% but less than 11% of the sampled plots. Prior to undertaking CCA, the length of the gradient, which is an estimate of species heterogeneity, was determined using Detrended Correspondence Analysis (DCA). When the length of the gradient from DCA is less than three standard deviations (SD), linear models such as Principal Component Analysis (PCA) and Redundancy Analysis (RDA) are appropriate. When the length of the gradient is greater than four SD, unimodal methods i.e. Correspondence Analysis (CA), Canonical Correspondence Analysis (CCA) and Detrended

Correspondence Analysis (DCA) are appropriate (Ter Braak and Smilauer, 2002). When the length of the gradient lies between three and four SD, either of the ordination methods that explain better can be used (Leps and Smilauer, 2003). Besides, the constrained or unconstrained nature of the ordination determines the ordination technique to be used (Ter Braak and Smilauer, 2002).

Exploration of the response of tree species to edaphic factors and distance from the forest edge involved application of DCA taking into account all the species that occurred in the sampled plots in all the five forest fragments. Preliminary DCA test revealed that the distribution and abundance of tree species exhibited unimodal responses to the edaphic factors and distance from the forest edge with gradient length of five standard deviations (SD). Since the gradient length was greater than four SD, CCA was found the most appropriate method for analysis (Ter Braak and Smilauer, 2002). The effect of edaphic factors and distance from the forest edge on the distribution and association of six dominant and adaptable tree species, most abundant and less abundant tree species involved the application of CCA with automatic forward selection using 1000 permutations. The determination of the influence of six dominant and adaptable tree species on the distribution of rare/less-abundant tree species also used CCA. Significance testing at the 95 % probability level made use of Monte-Carlo Permutation Test (MCPT).

Results

Variation of environmental variables along forest edge-interior gradient

The soil moisture content (%) varied significantly along the forest edge-interior gradient in Chawia ($F_{(1, 2)} = 47.47$; $p<0.001$), Fururu ($F_{(1, 2)} = 12.96$; $p<0.001$), Ngangao ($F_{(1, 2)} = 9.97$; $p<0.001$) and Vuria ($F_{(1, 2)} = 11.25$; $p<0.001$) (Table 2). However, no significant variations in soil moisture content were observed in Mbololo ($F_{(1, 2)} = 1.45$; $p=0.235$). Chawia had significantly higher soil moisture content in the forest interior while in Fururu and Ngangao, the intermediate forest exhibited significantly higher soil moisture content than the forest edge and interior. Soil moisture content in Vuria was higher at the edge of the forest than in the intermediate forest and forest interior.

Table 2: Comparison of mean soil moisture (percentage) along the forest edge-interior gradient for the five forest fragments in Taita Hills. The presented values are means with standard error of mean. Values with similar letters in superscripts in the same row are not significantly different at $p\leq0.05$ level

Forest fragment	Forest edge-interior gradient				
	Forest edge	Intermediate forest	Forest interior	*p* value	LSD
Chawia	1.50 ± 0.00^a	1.65 ± 0.04^a	2.23 ± 0.08^b	<0.001	0.171
Fururu	2.77 ± 0.15^b	3.51 ± 0.53^b	1.75 ± 0.11^a	<0.001	0.692
Mbololo	1.53 ± 0.05^a	1.64 ± 0.07^a	1.65 ± 0.04^a	0.235	0.154
Ngangao	1.25 ± 0.02^a	1.35 ± 0.02^b	1.24 ± 0.02^a	<0.001	0.057
Vuria	3.82 ± 0.44^b	2.56 ± 0.12^a	2.48 ± 0.12^a	<0.001	0.555

The results showed no significant variation in soil pH along the forest edge-interior gradient in Chawia ($F_{(1, 2)} = 0.36$; p=0.700) and Fururu ($F_{(1, 2)} = 0.41$; p=0.667). However, Mbololo ($F_{(1, 2)} = 15.48$; p=0.001) and Ngangao ($F_{(1, 2)} = 13.21$; p=0.001) had significantly higher soil pH at the edge of the forest than in the intermediate forest and the forest interior. Vuria had significantly lower soil pH at the edge of the forest than in the intermediate forest and the forest interior ($F_{(1, 2)} = 3.63$; p=0.042). The EC was not significantly different along the forest edge-interior gradient in Chawia ($F_{(1, 2)} = 0.11$; p=0.896), Mbololo ($F_{(1, 2)} = 1.01$; p=0.367), Ngangao ($F_{(1, 2)} = 0.60$; p=0.555) and Vuria ($F_{(1, 2)} = 0.15$; p=0.861). Fururu had significantly higher EC at the edge of the forest than the forest interior and intermediate forest ($F_{(1, 2)} = 3.44$; p=0.048) (Table 3).

Table 3: Comparison of mean soil pH and electrical conductivity along the forest edge-interior gradient for the five forest fragments in Taita Hills. The presented values are means with standard error of mean. Values with similar letters in superscripts in the same row are not significantly different at $p \leq 0.05$ level

Forest fragment	Soil property	Forest edge-interior gradient				
		Forest edge	**Intermediate forest**	**Forest interior**	***p* value**	**LSD**
Chawia	pH	5.58 ± 0.26^a	5.34 ± 0.14^a	5.62 ± 0.32^a	0.700	0.720
	EC (mS/cm)	0.107 ± 0.019^a	0.123 ± 0.019^a	0.116 ± 0.032^a	0.896	0.070
Fururu	pH	6.02 ± 0.19^a	6.01 ± 0.13^a	5.85 ± 0.10^a	0.667	0.430
	EC (mS/cm)	0.132 ± 0.021^b	0.080 ± 0.010^a	0.093 ± 0.011^{ab}	0.048	0.043
Mbololo	pH	6.10 ± 0.19^b	5.25 ± 0.17^a	4.79 ± 0.14^a	<0.001	0.475
	EC (mS/cm)	0.138 ± 0.022^a	0.174 ± 0.028^a	0.183 ± 0.021^a	0.367	0.067
Ngangao	pH	5.23 ± 0.102^b	4.69 ± 0.069^a	4.72 ± 0.077^a	<0.001	0.239
	EC (mS/cm)	0.155 ± 0.037^a	0.123 ± 0.017^a	0.121 ± 0.013^a	0.555	0.07
Vuria	pH	5.26 ± 0.09^a	5.64 ± 0.105^b	5.67 ± 0.153^b	0.042	0.351
	EC (mS/cm)	0.074 ± 0.008^a	0.069 ± 0.011^a	0.076 ± 0.009^a	0.861	0.028

In Chawia, there were no significant variations in organic carbon ($F_{(1, 2)} = 1.10$; p=0.345), nitrogen ($F_{(1, 2)} = 0.16$; p=0.855), phosphorus ($F_{(1, 2)} = 1.38$; p=0.265) and potassium ($F_{(1, 2)} = 2.44$; p=0.102) along the forest edge-interior gradient (Table 4). Similarly, no significant variations in organic carbon ($F_{(1, 2)} = 0.56$; p=0.576), nitrogen ($F_{(1, 2)} = 2.01$; p=0.156), phosphorus ($F_{(1, 2)} = 0.38$; p=0.690) and potassium ($F_{(1, 2)} = 1.67$; p=0.209) were observed in Vuria along the gradient from the edge of the forest to the forest interior. In Fururu, soil nitrogen was significantly higher at the forest edge than in the intermediate forest and the forest interior ($F_{(1, 2)} = 3.77$; p=0.038). However, organic carbon ($F_{(1, 2)} = 0.36$; p=0.703), phosphorus ($F_{(1, 2)} = 0.00$; p=0.997) and potassium ($F_{(1, 2)} = 1.35$; p=0.278) were not significantly different along the forest edge-interior gradient (Table 4). Potassium varied significantly along the forest edge-interior gradient in Mbololo ($F_{(1, 2)} = 6.58$; p=0.002) while organic carbon ($F_{(1, 2)} = 1.68$; p=0.192), nitrogen ($F_{(1, 2)} = 0.79$; p=0.458) and phosphorus ($F_{(1, 2)} = 0.85$; p=0.430) were not significantly affected by the edge effect. Similar to Mbololo, organic carbon ($F_{(1, 2)} = 1.17$; p=0.321), nitrogen ($F_{(1, 2)} = 1.05$; p=0.358) and phosphorus ($F_{(1, 2)} = 0.93$; p=0.404) showed no significant differences along the forest edge-interior gradient in Ngangao. However, potassium was significantly higher at the edge of the forest than in the intermediate forest and forest interior ($F_{(1, 2)} = 3.64$; p=0.035) (Table 4).

Table 4: Comparison of mean organic carbon, nitrogen, phosphorus and potassium along the forest edge-interior gradient for the five forest fragments in Taita Hills. The presented values are means with standard error of mean. Values with similar letters in superscripts in the same row are not significantly different at $p \leq 0.05$ level. OC = Organic Carbon (%); N = Nitrogen (%); P = Phosphorus (ppm) and K = Potassium (ppm)

Forest fragment	**Soil property**	**Forest edge**	**Intermediate forest**	**Forest interior**	***p* value**	**LSD**
Chawia	OC (%)	6.98 ± 0.86^{a}	6.94 ± 0.98^{a}	9.52 ± 2.06^{a}	0.345	4.05
	N (%)	0.59 ± 0.17^{a}	0.63 ± 0.15^{a}	0.72 ± 0.18^{a}	0.855	0.48
	P (ppm)	5.0 ± 0.58^{a}	7.0 ± 1.26^{a}	11.0 ± 4.62^{a}	0.265	8.0
	K (ppm)	120.87 ± 15.39^{a}	89.74 ± 9.16^{a}	88.14 ± 9.85^{a}	0.102	33.96
Fururu	OC (%)	4.94 ± 0.78^{a}	4.17 ± 0.65^{a}	4.74 ± 0.62^{a}	0.703	2.025
	N (%)	0.79 ± 0.04^{b}	0.64 ± 0.05^{ab}	0.57 ± 0.08^{a}	0.038	0.17
	P (ppm)	5.0 ± 1.02^{a}	5.0 ± 0.64^{a}	5.0 ± 0.40^{a}	0.997	2.20
	K (ppm)	111.96 ± 21.12^{a}	77.81 ± 13.06^{a}	83.79 ± 11.0^{a}	0.278	46.45
Mbololo	OC (%)	9.14 ± 0.92^{a}	10.08 ± 1.01^{a}	11.56 ± 0.87^{a}	0.192	2.641
	N (%)	0.81 ± 0.078^{a}	0.81 ± 0.08^{a}	0.93 ± 0.08^{a}	0.458	0.23
	P (ppm)	14.0 ± 1.84^{a}	12.0 ± 1.63^{a}	15.0 ± 1.75^{a}	0.430	4.9
	K (ppm)	222.20 ± 31.92^{b}	143.10 ± 15.77^{a}	112.60 ± 13.82^{a}	0.002	62.09
Ngangao	OC (%)	6.91 ± 0.68^{a}	7.09 ± 0.80^{a}	8.59 ± 1.05^{a}	0.321	2.44
	N (%)	0.60 ± 0.07^{a}	0.53 ± 0.06^{a}	0.67 ± 0.06^{a}	0.358	0.19
	P (ppm)	8.0 ± 1.32^{a}	12.0 ± 2.79^{a}	11.0 ± 1.44^{a}	0.404	5.60
	K (ppm)	96.48 ± 15.94	54.16 ± 6.04^{a}	72.35 ± 8.96^{ab}	0.035	31.7

		b				4
Vuria	OC (%)	5.591±0.44[a]	4.84±0.60[a]	5.12±0.44[a]	0.576	1.47
	N (%)	0.58±0.06[a]	0.57±0.06[a]	0.45±0.04[a]	0.156	0.16
	P (ppm)	18.0±4.26[a]	23.0±4.81[a]	23.0±5.24[a]	0.690	14.0
	K (ppm)	163.10±36.51[a]	246.50±38.83[a]	221.50±21.26[a]	0.209	96.69

Interaction between dominant and adaptable tree species and environmental variables

Canonical Correspondence Analysis (CCA) model for the relationship between the six dominant and adaptable species (*Macaranga conglomerata*, *Albizia gummifera*, *Syzygium guineense*, *Xymalos monospora*, *Tabernaemontana stapfiana* and *Maesa lanceolata*) and environmental variables (MCPT; 1000 Permutations) was significant for distance from the forest edge ($F_{(1000)} = 2.76$; p=0.012), EC ($F_{(1000)} = 2.53$; p=0.028), potassium ($F_{(1000)} = 2.39$; p=0.031) and soil moisture ($F_{(1000)} = 2.46$; p=0.037). However, soil pH ($F_{(1000)} = 2.15$; p=0.068), nitrogen ($F_{(1000)} = 0.41$; p=0.838), phosphorus ($F_{(1000)} = 1.50$; p=0.187) and organic carbon ($F_{(1000)} = 0.22$; p=0.947) were not significant in the model.

Albizia gummifera had large abundance within the forests' areas whose soils were saline and had high organic carbon content (Fig. 2). However, there was a negative correlation for *A. gummifera* with soil moisture. Phosphorus and nitrogen had a large positive correlation with *M. conglomerata*. *Xymalos monospora* was more abundant in areas within the forests that had high concentration of potassium in soil. Moreover, soil moisture had a positive relationship with *X. monospora*. *Tabernaemontana stapfiana* had large positive correlation with soil pH and distance from the forest edge. *Syzygium guineense* had a positive relationship with organic carbon and EC. However, the abundance of *M. lanceolata* exhibited no correlation with the environmental variables.

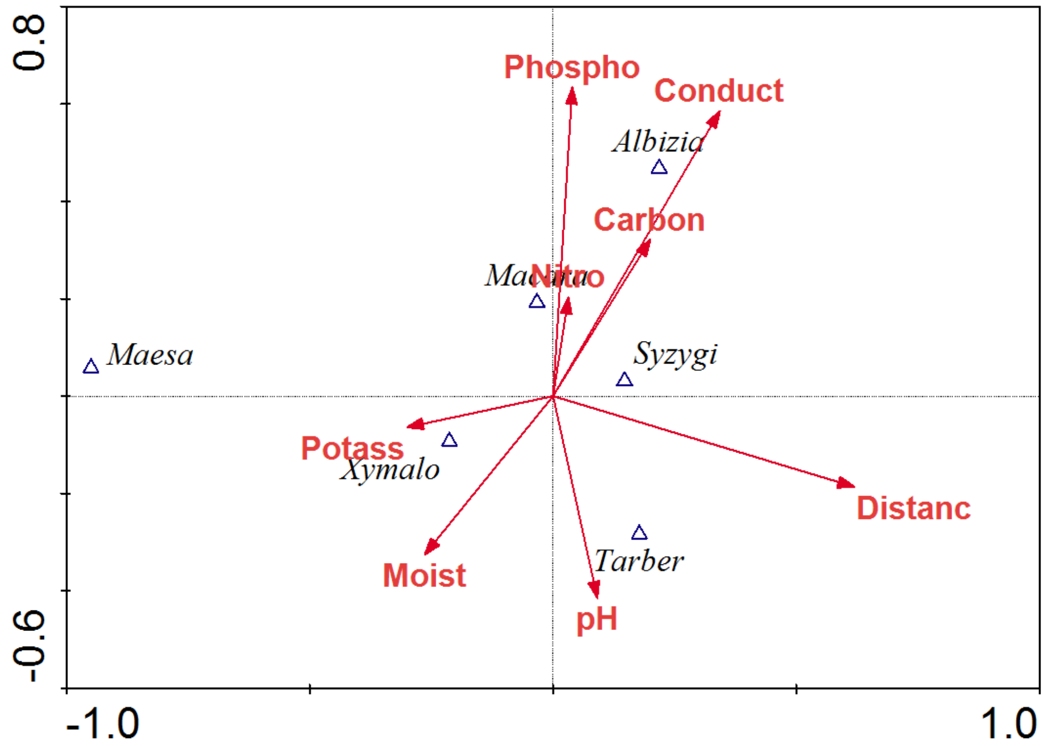

Figure 2: Canonical Correspondence Analysis (CCA) triplot of six adaptable and dominant tree species and environmental variables in five forest fragments, Taita Hills. Potass = Potassium, Moist = Soil moisture, Conduct = Electrical conductivity, Distanc = Distance from forest edge, Phospho = Phosphorus, Nitro = Nitrogen

Interaction between most abundant tree species and environmental variables

The CCA model was significant for EC ($F_{(1000)} = 3.48$; p=0.001), distance from forest edge ($F_{(1000)} = 2.89$; p=0.001) and soil pH ($F_{(1000)} = 1.77$; p=0.020). However, the CCA model was not significant for potassium ($F_{(1000)} = 1.60$; p=0.064), phosphorus ($F_{(1000)} = 0.98$; p=0.461), moisture ($F_{(1000)} = 1.48$; p=0.087), organic carbon ($F_{(1000)} = 1.47$; p=0.081) and nitrogen ($F_{(1000)} = 1.56$; p=0.052). The distance from the forest edge had a highly positive correlation with species such as *Tabernaemontana stapfiana*, *Psychotria petitii*, *Chassalia discolor*, *Newtonia buchananii*, *Oxyanthus speciosus*, *Pauridiantha paucinervis* and *Strombosia scheffleri* among other species (Fig. 3). There was a strong positive correlation between potassium and *Xymalos monospora*, *Lepidotrichilia volkensii*, *Cussonia spicata* and *Neoboutonia macrocalyx*. *Dasylepis integra*, *Brucea antidysenterica*, *Garcinia volkensii*, *Phoenix reclinata* and *Pleiocarpa pycnantha* had a high positive correlation with soil pH. Phosphorus had a large positive correlation with *Turraea holstii* and *Millettia oblata*. The EC and nitrogen had a strong positive relationship with *Albizia gummifera* and *Cola greenwayi* whereas *Crabia zimmermannii* exhibited slightly positive correlation with organic carbon. There was no relationship between *Rytigynia uhligii* and *Maytenus senegalensis* with any of the environmental variables studied.

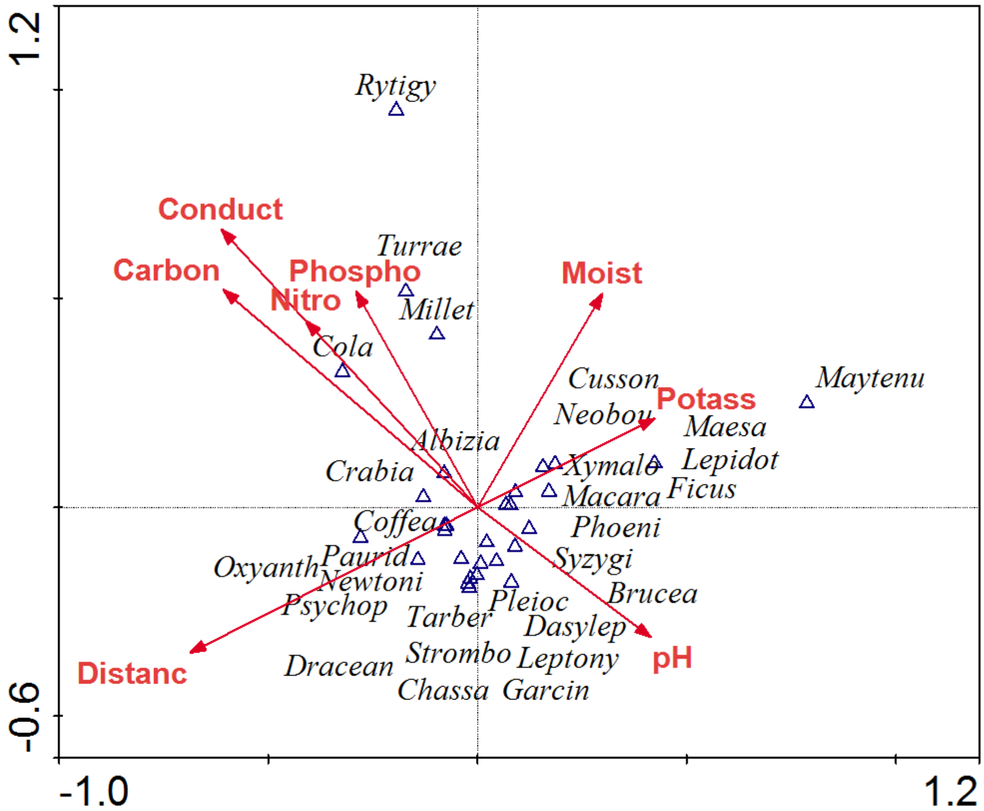

Figure 3: Canonical Correspondence Analysis (CCA) of most abundant tree species and environmental variables for the five forest fragments in Taita Hills. Potass = Potassium, Moist = Soil moisture, Conduct = Electrical conductivity, Distanc = Distance from forest edge, Phospho = Phosphorus, Nitro = Nitrogen

Interaction between less abundant tree species and environmental variables

The CCA model was significant for soil moisture ($F_{(1000)} = 3.30$; p=0.044), nitrogen ($F_{(1000)}$ = 2.02; p=0.017) and distance from the forest edge ($F_{(1000)}$ = 1.96; p=0.021). However, the model was not significant for organic carbon ($F_{(1000)}$ = 1.37; p=0.202), EC ($F_{(1000)}$ = 0.79; p=0.658), soil pH ($F_{(1000)}$ = 0.70; p=0.754), potassium ($F_{(1000)}$ = 0.66; p=0.752) and phosphorus ($F_{(1000)}$ = 0.43; p=0.934). Less abundant species such as *Prunus africana* and *Allophylus abyssinicus* showed a highly positive correlation with nitrogen and phosphorus (Fig. 4). *Podocarpus latifolius*, *Ochna holstii*, *Aphloia theiformis* and *Polyscias fulva* had positive correlation with organic carbon, EC and distance from the forest edge. *Lobelia giberroa* had a high positive correlation with soil moisture and potassium. *Vernonia auriculifera* and *Agelaea pentagyna* had a strong positive correlation with soil pH. Similarly, *Aningeria robusta* and *Sorindeia madagascariensis* were correlated with soil pH.

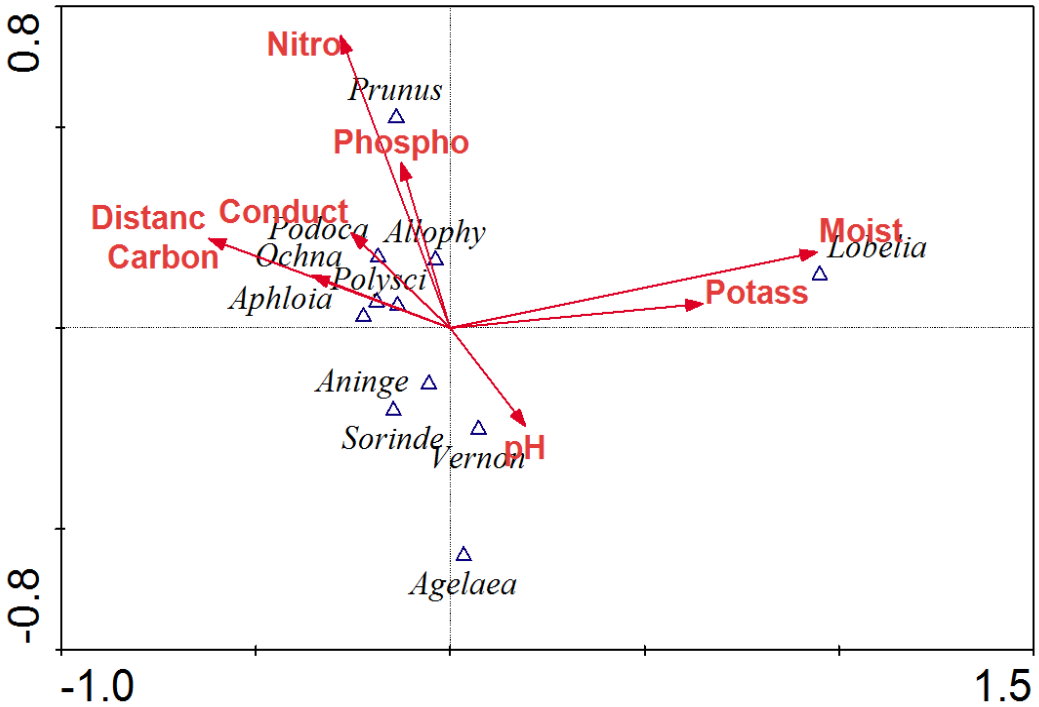

Figure 4: Canonical Correspondence Analysis (CCA) of less abundant tree species and environmental variables in the five forest fragments of Taita Hills. Potass = Potassium, Moist = Soil moisture, Conduct = Electrical conductivity, Distanc = Distance from forest edge, Phospho = Phosphorus, Nitro = Nitrogen

Discussion

Effects of forest edge on environmental variables

The results support our hypothesis that soil physical and chemical properties were dependent on the distance from the forest edge. The distance from the forest edge strongly influenced soil moisture along forest edge-interior gradient. In Chawia, Fururu, Ngangao and Mbololo, soil moisture was higher in the intermediate forest and forest interior than on the forest edges. Many studies (Camargo and Kapos 1995; Laurance *et al.*, 1998; Laurance *et al.*, 2000; Baimas-George, 2012) have shown that soil moisture is higher in the forest interior than on edge. Contrary to most studies, soil moisture in Vuria decreased towards the forest interior most likely because of very steep gradient that increased sharply towards the forest interior affecting soil moisture adversely as previously demonstrated by Huat *et al.* (2006).

The soil pH also varied with distance from the forest edge. In Fururu, Mbololo and Ngangao, the soil pH was moderately acidic at the forest edge but strongly acidic in the forest interior. This is in agreement with findings of previous studies which have shown that soil pH declines from forest edge to the interior (Aerts *et al.*, 2006; Wuyts *et al.*, 2013). The soil pH was moderately acidic on the forest edge, intermediate forest and forest interior in Chawia and Vuria. Chawia and Vuria are heavily disturbed (Pellikka *et al.*, 2009; Wekesa *et al.*, 2016), and therefore, the ecological conditions on the forest edges and in the intermediate forest and forest interior does not differ much; this could explain the similarity in soil pH along forest edge-interior gradient. The EC was not affected by the distance from the forest edge in Chawia, Mbololo, Ngangao and Vuria. However, the EC was higher on the forest edge than in the forest interior and intermediate forest in Fururu. Unlike Chawia, Mbololo, Ngangao and Vuria which are surrounded by roads and fallow lands, Fururu is surrounded by intensively cultivated farms. There is heavy use of inorganic fertilizers in the cultivated farms surrounding Fururu and that is why the EC was higher at the edge of the forest than in the forest interior. The EC is dependent on the cation exchange capacity and salinity level in the soil and therefore, application of inorganic fertilizers increases the EC and pH of the soil (Grisso *et al.*, 2009).

Nitrogen content in the soil was affected by the distance from the forest edge and hence varied along forest edge-interior gradient. In Chawia and Mbololo, nitrogen increased towards the forest interior while in Fururu and Vuria, it decreased towards the forest interior. In Ngangao, nitrogen was higher in the forest interior and lower in the intermediate forest. The scenario in Chawia, Mbololo and Ngangao where nitrogen content was higher in the forest interior than on the forest edge is congruent with finding of previous studies (Jose *et al.*, 1996; Aerts and Chapin, 2000; Laurance *et al.*, 2000; Toledo-Aceves and García-Oliva, 2007). In contrast, the decrease in nitrogen content towards the forest interior in Fururu and Vuria was because of two reasons. Firstly, the soils become shallower towards the interior due to the presence of numerous rocks in the interior of Fururu and Vuria as the elevation increases. The shallow soils encumber rapid mineralization of organic matter leading to low nitrogen in the forest interior. Secondly, Fururu is surrounded by intensively cultivated farmlands. The farmlands are regularly cultivated for food crops using inorganic fertilizers. The forest edges that border these inorganically fertilized agricultural farmlands receive nitrogen from fertilizer inputs (Pocewicz and Penelope, 2007) increasing the nitrogen level on the forest edge.

The level of organic carbon in the soil was dependent on the distance from the forest edge. In Mbololo and Ngangao, organic carbon increased towards forest interior. Other related studies have shown that forest edge soils have significantly lower percentage carbon than forest interior soils (Redding *et al.*, 2003; Toledo-Aceves and García-Oliva, 2007; Bergès *et al.*, 2013). On the other hand, organic carbon was higher on the forest edges in Chawia, Fururu and Vuria than in the intermediate forest and forest interior. This diverges from earlier reports that showed forest edge soils have lower organic carbon than the forest interior (Redding *et al.*, 2003; Toledo-Aceves and García-Oliva, 2007; Bergès *et al.*, 2013). Seemingly, the size of the forest fragment influenced the organic carbon dynamics along the forest edge-interior gradient. The small fragments of Chawia, Fururu and Vuria had similar trends for organic carbon levels in the soil along the forest edge-interior gradient, a phenomenon that was also manifested in large forest fragments of Mbololo and Ngangao.

The distance from the forest edge influenced the concentration of phosphorus in the soil. The level of phosphorus was higher in the forest interior than on the forest edges in Chawia, Mbololo, Ngangao and Vuria signifying that the rocks in these forest fragments were of different types along the forest edge-interior gradient. The present results are in agreement with findings by several authors who have indicated that available phosphorus increases towards forest interior (Jose *et al*., 1996; Laurance *et al*., 2000; Baimas-George, 2012). However, phosphorus level in Fururu was the same at the forest edge, intermediate forest and forest interior clearly indicating that the rocks occurring in this particular forest were of the same type along the forest edge-interior gradient (Cerozi and Fitzsimmons, 2016). Phosphorus levels in Chawia, Fururu, Mbololo and Ngangao were deficient for plant growth (<20 ppm). However, in Vuria, the level of phosphorus was sufficient for plant growth (>20 ppm). According to Okalebo *et al*. (2002), sufficient levels of phosphorus in the soils range between 20 and 30 ppm. The variation in phosphorus along forest edge-interior gradient could be attributed to the differences in soil pH (Omoro *et al*., 2011; Cerozi and Fitzsimmons, 2016). Soil pH varies with distance from the forest (Marchand and Houle, 2006) and strongly influences the available phosphorus in tropical forests' soils (Brady, 1984). The difference in the types of rocks was responsible for the variation of phosphorus among the forest fragments as reported by Cross and Schlesinger (1995).

Potassium level in the soil differed between forest edge and the forest interior. In Chawia, Fururu, Mbololo and Ngangao, potassium in the soil was high on the forest edge than in the intermediate forest and forest interior. Prior studies by Bunyan *et al*. (2012) revealed that available potassium in the soil increases with increasing distance from the forest edge. The results of this study disagree with findings by Bunyan *et al*. (2012). The present result showing that the level of potassium increased towards forest interior in Vuria agrees with previous findings by Bunyan *et al*. (2012). Potassium was adequate on the forest edge but deficient in the intermediate forest and the forest interior in Chawia. The situation was different in Fururu and Ngangao where potassium was deficient at the forest edge, in the intermediate forest and the forest interior. In Mbololo, potassium was adequate on the forest edge and in the intermediate forest but deficient in the forest interior while in Vuria, it was adequate at the forest edge, in the intermediate forest and forest interior. The variation in potassium along forest edge-interior gradient and among the forest fragments was attributed to the variation in soil pH and moisture. Soil pH and moisture influence the level of potassium in the soil (Ranade-Malvi, 2011; Maeda, 2012).

A key result of this study was the observation that among the five forest fragments studied, only Vuria had sufficient levels of phosphorus (≥20 ppm) and potassium (≥117.3 ppm) on the forest edge, in the intermediate forest and forest interior. This means phosphorus and potassium were the nutrients that limited the growth of trees and other plants in the other four forest fragments (Chawia, Fururu, Mbololo and Ngangao). The results reinforces the findings of Vitousek (1984), Wright *et al.* (2011) and Omoro *et al.* (2011) which reported that phosphorus and potassium are most critical soil nutrients limiting growth of trees and other plants in tropical forests.

Interaction between dominant and adaptable tree species and environmental variables

The distribution and abundance of *M. conglomerata*, *A. gummifera*, *S. guineense*, *X. monospora*, *T. stapfiana* and *M. lanceolata* sturdily depended on the distance from the forest edge, EC, potassium and soil moisture levels in the soil. This confirms the hypotheses that the distance from the forest edge and soil properties affect the distribution and abundance of tree species along forest edge-interior gradient. Other related studies (Jules, 1998; Tomimatsu and Ohara, 2003) have shown that tree species in natural forests are positively correlated to distance to the edge. Moreover, studies by Cadenasso *et al.* (1997), Gehlhausen *et al.* (2000), Laurance (2007) and Aerts *et al.* (2011) have shown that tree species abundance is correlated to environmental variables such as soil moisture and potassium, variables that often vary with distance from the forest edge (Cadenasso *et al.*, 1997; Laurance, 2007; Aerts *et al*., 2011). Nadeau and Sullivan (2015) have also reported that tree species richness in tropical forests is inversely related to the concentration of potassium, calcium and cation exchange capacity.

EC is a measure of soil salinity and therefore, positive or negative changes in soil salinity can affect the distribution and abundance of woody species in tropical forests (Zefferman *et al.*, 2015). Thus, soil salinity affected growth and, distribution and abundance of the six species through ion toxicity, effects on osmotic potential and interference with plant nutrition (Zefferman *et al.*, 2015).

The present results also indicate that soil pH, nitrogen, phosphorus and organic carbon did not influence the distribution and abundance of *M. conglomerata*, *A. gummifera*, *S. guineense*, *X. monospora*, *T. stapfiana* and *M. lanceolata*. This was expected because in tropical forests, nitrogen and organic carbon are sufficiently available for absorption and use by trees (Omoro *et al.*, 2011) and hence play a minor role in the distribution and abundance of tree species (Omoro *et al.*, 2011). In this study, the observation that soil pH did not influence the distribution of abundance of the six species contradicts findings by John *et al.* (2007) which indicated that soil pH indirectly exerts strong influence on species distributions in tropical forests by influencing the availability of several plant nutrients. In this case, the soil pH did not exert strong influence on the nutrients required for the growth of the six species. Despite the fact that phosphorus is the nutrient that limits the growth of trees and other plants in tropical forests (Vitousek, 1984; Wright *et al.*, 2011; Omoro *et al.*, 2011), the distribution and abundance of the six dominant and adaptable tree species was not affected by this particular soil variable. There is evidence in the literature that phosphorus availability in Afromontane forests in the tropics can be low and declines with elevation (Tanner *et al.*, 1998; Benner *et al.*, 2010). However, efficient cycling of phosphorus through higher resorption efficiency of phosphorus as the plants tissues senesce makes the nutrient available to the plants in sufficient quantities (Dalling *et al.*, 2016). The six species seems to have inherent mechanisms that enhance efficient cycling of phosphorus increasing phosphorus available to them. As a result, the distribution and abundance of the species were not affected by the limitation of phosphorus observed in the fragmented forests of Taita Hills.

Interaction between most abundant tree species and environmental variables

Unlike the six dominant and adaptable species whose abundance was mainly influenced by the distance from the forest edge, electrical conductivity, potassium and soil moisture, the probability of occurrence of the thirty tree species categorized as most abundant (six dominant and adaptable species included) was mainly influenced by the distance from forest edge, potassium and soil pH. Besides, EC, nitrogen, phosphorus and organic carbon marginally affected the probability of occurrence of the most abundant tree species. Soil moisture did not affect distribution and abundance of most abundant trees species. The distance from the forest edge influenced distribution and abundance of 36.7 % of the species classified as most abundant species followed by potassium (23.3 %), soil pH (20.0 %), phosphorus (6.7 %) and organic carbon (3.3 %). The EC and nitrogen collectively accounted for 6.7 % of species distribution and abundance for the most abundant tree species. The distribution and abundance of the remaining 3.3 % of the most abundant species was not dependent either on any of the environmental variables studied or the distance along forest edge-interior gradient. This is consistent with findings of Gruszczynska *et al.* (1991), Vitousek *et al.* (1996) and Omoro *et al.* (2011), which indicated that soil variables are not the only abiotic factors that affect spatial differentiation of plant communities; instead, other factors such as geologic and anthropogenic activities influence the spatial abundance of plant species.

The distance along forest edge-interior greatly influenced the distribution and abundance of most abundant species and this was mainly due to the edge effects (Bennett and Saunders, 2010; Magnago *et al.*, 2015). Moreover, tree species are habitually associated with soils that differ in several physical, chemical and biotic properties (Ayres *et al.*, 2009) and these soil properties vary along forest edge-interior gradient (Bergès *et al.*, 2013). Previous studies have shown that there is a sturdy correlation between potassium and woody species distribution and abundance in tropical forests (Tripler *et al.*, 2006). Moreover, phosphorus is a critical nutrient that limits the growth of forest plants in tropical forests and hence strongly affects tree species distribution and abundance (Vitousek, 1984; Baribault *et al.*, 2012; Li *et al.*, 2013; Dalling *et al.*, 2016). Other related studies have also revealed that soil pH level that increases phosphorus availability promotes the co-existence of tree species affecting their distribution and abundance within a forest community (Xu *et al.*, 2016). Therefore, the large variation in soil properties and ecological functioning along the forest edge-interior gradient explains the great influence of distance from forest edge on species distribution.

The results of this study indicate that organic carbon, EC and nitrogen did not affect the distribution and abundance of the most abundant tree species. This is because soil organic carbon and nitrogen are typically adequate in tropical forests and hence play a minor role in the distribution and abundance of tree species (Omoro *et al.*, 2011). Similarly, EC did not affect the distribution and abundance of most abundant tree species because the values were within the normal range required by plants for successive growth. Studies on interaction between EC and species distribution and abundance in the tropics are rare and therefore we could not find related research findings to allow us make comparison with the present results.

The distribution and abundance of a small proportion of most abundant species (3.3 %) was not affected by both environmental variables and the distance from forest edge. Therefore, other factors such as geodynamic and anthropogenic activities may have affected the spatial distribution and occurrence of these particular species (Gruszczynska *et al.*, 1991; Vitousek *et al.*, 1996).

Interaction between less abundant tree species and environmental variables

This study revealed that the occurrence of eleven tree species categorized as less abundant was majorly affected by organic carbon, EC, soil pH, nitrogen, phosphorus and distance from forest edge. Soil moisture and potassium marginally affected the occurrence of less abundant species. Distance from the forest edge, organic carbon and EC affected the distribution and abundance of 36.4 % of the less abundant species. Similarly, soil pH affected the distribution and abundance of 36.4 % of the less abundant species. Nitrogen and phosphorus affected the distribution and abundance of 18.2 % of the less abundant species while soil moisture and potassium were collectively responsible for the occurrence of 9.1% of the less abundant species. Clearly, the distribution and abundance of the less abundant species was not dependent on only one specific environmental variable but rather on a combination of either two or more variables (Aerts *et al.*, 2006; Laurance, 2007). This is in contrast with most abundant tree species whose distribution and abundance were mostly dependent on one environmental variable. Therefore, interactions among various environmental variables are very important in maintaining the diversity of less abundant tree species in the fragmented forests of Taita Hills.

Implications on management of fragmented forests

The results of this study highlight the fact that soils on the edges of Taita Hills' forest fragments are of low fertility, and have low moisture content. These factors are likely to be strongly limiting natural regeneration of indigenous species at the forest edges (Benitez-Malvido, 1998; Bruna, 1999) and hence reducing species richness and diversity (Kacholi, 2014). Moreover, moisture-stressed trees on the forest edges shed leaves, and because of drier edge conditions, the rate of litter decomposition is slow (Didham, 1998). Accumulating litter affects seed germination (Bruna, 1999) and seedlings survival (Scariot, 2001) and makes forest edges vulnerable to surface fires during droughts (Cochrane *et al.*, 1999). Under such conditions, establishment of agroforestry belts on the boundaries of the forest fragments to ameliorate the adversarial microclimatic conditions created on the forest edges due to the edge effect is likely to be a wiser management strategy from a long-term perspective. The amelioration of micro-climatic conditions on the forest edges can create favourable conditions for secondary forest growth and hence enhancing resilience of the forest fragments to the edge effects and conserving the remaining biodiversity.

The distribution and abundance of tree species were mainly influenced by distance from the forest edge, soil moisture, nitrogen, EC and potassium. The knowledge on the relationships between the five environmental variables and tree species should be utilized in developing effective restoration strategies able to produce self-sustaining forests that promotes biodiversity conservation and ecosystem function (Gibson *et al.*, 2011; Magnago *et al.*, 2014). This is because successful restoration activities are based on solid scientific information (Rodrigues *et al.*, 2009). Besides, soil properties-tree species relationships established in this study should be used in selecting suitable native species for restoration programmes (Omoro *et al.*, 2011). The Taita Hills forest fragments are moderately-heavily disturbed with heavy presence of gaps (Omoro *et al.*, 2010; Omoro *et al.*, 2011; Wekesa *et al.*, 2016), and therefore, planting of suitable tree species, well adapted to particular soil conditions is likely to facilitate and accelerate recovery of degraded sites within the forest fragments leading to rapid successional development.

Conclusions

This study tested the hypotheses that environmental variables (soil moisture, organic carbon, phosphorus, soil pH, electrical conductivity, nitrogen and potassium) are different on the forest edge, intermediate forest and forest interior, and that the distribution and abundance of tree species reflects the changes in environmental variables along forest edge-interior gradient. The edge effect greatly influenced environmental variables along forest edge-interior gradient. The environmental variables interacted with one another and with distance from the forest edge and the interactions influenced the distribution and abundance of tree species along the forest-edge-interior gradient. The distribution and abundance of six dominant and adaptable species (*M. conglomerata*, *A. gummifera*, *S. guineense*, *X. monospora*, *T. stapfiana* and *M. lanceolata*) were mainly influenced by distance from the forest edge, EC, potassium and soil moisture. Moreover, the distribution and abundance of the other tree species (six dominant and adaptable species excluded) was mainly influenced by nitrogen, EC, the distance from forest edge and soil pH. Overall, distance from the forest edge, soil moisture, nitrogen, EC and potassium were the key environmental variables that determined species distribution and abundance in forest fragments of Taita Hills. Therefore, restoration efforts including enrichment planting should take into consideration the relationships between environmental variables and tree species in selecting suitable and better adapted species for optimal establishment, survival and growth of planted seedlings to enhance recovery.

Acknowledgments

The authors would like to thank African Forest Forum (AFF) and Kenya Forestry Research Institute through Forest Biodiversity and Environment Management thematic area for funding this study. Special thanks to Kenya Forest Service, Wundanyi Forest Station for their support during setting up of the studies and data collection. We also thank the field crew: Joseph Muthini, Jonam Mwandoe, Rita Mulatya, Felvine Otieno, Gabriel Mwarabu and John Mbori for their effort during data collection. Finally, we acknowledge the administrative and logistical support received from the Regional Director and Deputy Regional Director, Kenya Forestry Research Institute, Coast Eco-Region Research Programme.

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Effect of Water Conservation Method on the Yield of Coconuts

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Abstract

The coconut palm *(Cocos nucifera)* is a perennial tree crop that is widely cultivated in more than 86 tropical countries of the world with a total production of 54 billion nuts per year (FAO, 2013). The palm produces nuts throughout the year when climatic conditions are favorable and is one of the most important food security crops. Kenya is suitable for the growing of the coconut palm and its production is mainly carried out along the Kenyan coastal region. Coconut has the potential to substitute 30% of the edible oil imports into the country. However, to achieve this target; there is need to address the effects of climate change that affect coconut production. The unreliability of rainfall being experienced in Coastal Kenya has contributed to low productivity as well as death of many coconut trees. A water harvesting structure (digging of a trench around the coconut tree) as well as moisture conservation technologies trial was conducted in a coconut tree plantation and replicated three times in a randomized complete block design in order to determine the most suitable water harvesting technology. Results indicate that the number of coconuts that were harvested in the treatment of 'water harvesting plus green manure incorporation' was significantly different ($P<0.05$) compared to other treatments. However, the weight of nuts in the treatment of water harvesting and farmyard manure application was higher than the rest. The number of nuts and their resultant weights in the treatment of water harvesting and manure application was directly proportional.

Keywords: Coconuts, water harvesting, Coastal Kenya

Introduction

The coconut palm *(Cocos nucifera)* is a perennial tree crop that is widely cultivated in more than 86 tropical countries of the world with a total production of 61 billion nuts per year (FAO, 2013). The palm produces nuts throughout the year when climatic conditions are favorable and is one of the most important food security crops. The palm is also regarded as the tree of life owing to its wide range of over 120 products for domestic and international markets. These products include; edible and non-edible oils, fibre of commercial value, coconut shell for fuel and industrial uses, thatching materials (*makuti*), palm wine (toddy), brooms, and timber for construction and furniture making (Sharma, 2006). The edible oil is also used for medicinal purposes as it contains lauric acid which is reported to slow down multiplication of the HIV virus and reduce the mother to child transmission of HIV (Anon, 1999 and 2001; Fife, 2005*)*. It is also reported that populations that use coconut oil have lowest rates of heart diseases and cancer (Fife, 2005). Coconut at the same time plays a major role as food, providing 15% of calories and 5% protein in the food basket.

Coconut production is mainly carried out along the Kenyan coastal region and has the potential to substitute 30% of the edible oil imports into the country (FAO, 2007). Besides growing in the coastal belt, coconut can also grow in Taita Taveta which though not close to the coastline has suitable conditions for its cultivation. Other areas with potential for coconut production include; Busia and Homa Bay in the Lake Victoria region, and Tharaka Nithi in Eastern region. These areas have high rural poverty and malnutrition rates. Introduction and promotion of this crop in these areas can provide alternative sources of nutritious food and income to the communities.

The total area under coconut farming in Kenya is estimated to be 200,000 acres, with a population of 10 million trees that produce slightly over 260 million nuts per year. There is an increasing demand for coconuts and coconut products in the country and the neighboring countries of Uganda and Tanzania. This therefore calls for an increase in the area under coconut production as the coconut tree has the potential to offer many opportunities that include employment creation through the development of cottage industries for both edible and non-edible products. Additionally, the tree has the potential of protecting the environment from the adverse effects of climate change by acting as a carbon sink and consequently reducing global warming.

The coconut sub-sector in Kenya has been faced with a number of challenges. These include; poor crop husbandry, aged/senile trees, inadequate access to quality planting materials, cutting of coconut trees, pests and diseases, narrow genetic base, inadequate and unreliable rainfall and the effects of climate change (CC). The unreliability of rainfall being experienced in Coastal Kenya and the country at large has led to unprecedented seasonal shifts and in turn contributed to low productivity as well as death of many coconut trees. Over the past 10 years, the rainfall being experienced in the country has continued to decrease in amount and predictability (Mwanga, 2015).

Decreasing rainfall and its unpredictability is leading to gradual decline in yields per tree per year with an average production of 260 million nuts per year. Effects of declining coconut yields are diverse including inadequate raw material supply to the agro-based industries in the sub-sector. The declining yields is leading to low attraction of investment to the coconut industry. There is need therefore to mitigate against the effects of climate change by coming up with technological interventions that target at increasing production and quality of nuts produced.

One such intervention is the conservation of water during the rainy season in a bid to prolonging availability of moisture to the trees during the dry seasons. Such water conservation effort would also ensure continued nut production throughout the year. Some of the water conservation methods such as mulching have the additional advantage of improving the soil organic matter and soil fertility. A study was therefore undertaken to test various water harvesting and conservation technologies on coconut trees and determine the most effective ones based on yields of nuts.

Materials and methods

Site Description

The study was conducted at the Kenya Agricultural Research Institute (KARI) centre-Matuga situated in Kwale County of Coastal Kenya. The site is 120 m above sea level and lies at latitude 4 ^{o} 10'N and 39^{o} 34'E. The rainfall pattern is bi-modal with peaks in May and November during the long and short rain seasons respectively. Average annual rainfall is 720 mm. The mean monthly maximum and minimum temperatures are 34^{o}C and 21^{o}C respectively. The soils are red sandy loams that are deep and well drained.

The trial was conducted within an existing coconut plantation. The plantation was established in 1965 in an area measuring 2 acres. Low coconut yields had been recorded 3 years prior with less than 30 nuts per tree per year owing to low moisture levels as a result of the low rainfall amounts.

Experimental procedures

The land within the coconut plantation was ploughed and later harrowed by use of a tractor to ensure uniformity of moisture conservation. Some water harvesting structures were constructed at the base of each coconut tree. This was done by digging a trench around the coconut tree measuring 30 cm wide and 15 cm deep at a radius of 1.5 m from the base of the coconut tree. The trenches were meant to havest the water from the coconut tree canopies as it rained. The mature nuts in each tree were harvested and their numbers together with their respective total weights were recorded.

Treatments and Treatment combinations

The treatments were administered in the tree trenches of the coconut plants with each row having a different treatment from the other. The treatments were administered in a Randomized Complete Block Design and were then replicated three times. The treatments administered are as described in the table below and were randomized in each of the block.

Table 1. Treatments Descriptions

Treatment No.	Description
1	Digging a trench around the coconut tree measuring 30 cm wide and 15 cm deep at a radius of 1.5 m from the base of the coconut tree and applying 2 buckets of cattle manure in the trench and covering it.
2	Digging a trench around the coconut tree measuring 30 cm wide and 15 cm deep at a radius of 1.5 m from the base of the coconut tree, filling the trench with dried coconut husks and covering it.
3	Digging a trench around the coconut tree measuring 30 cm wide and 15 cm deep at a radius of 1.5 m from the base of the coconut tree, planting cowpeas within the base of the tree to the trench to act as a cover crop.
4	Digging a trench around the coconut tree measuring 30 cm wide and 15 cm deep at a radius of 1.5 m from the base of the coconut tree, filling the trench with dry grass and covering it.
5	Digging a trench around the coconut tree measuring 30 cm wide and 15 cm deep at a radius of 1.5 m from the base of the coconut tree, planting cowpeas within the trench and incorporating it with soil as green manure after one month from the date of planting.
6	Digging a trench around the coconut tree measuring 30 cm wide and 15 cm deep at a radius of 1.5 m from the base of the coconut tree, applying 2 kgs of DAP fertilizer within the trench and covering it.
7	Control. No digging of a trench around the coconut tree

Plot layout

The experiment was replicated in three blocks of 10 plots each. The plots measured 9 x 10 m in each block making a total of 30 plots. Each of the 10 treatments was randomly assigned in the plots for each of the blocks. The experimental design was Randomized Complete Block Design (RCBD) with 3 replications. Each block was separated by a 4 m path while the plots within the blocks were separated by a 3 m path (Figure 1).

CITRUS ORCHARD							
Tree line No.	1	2	3	4	5	6	7
Block I Randomized treatments within blocks	2	4	5	7	1	3	6
PATH							
Block II Randomized treatments within locks	7	6	4	3	5	1	2
PATH							
Block III Randomized treatments within blocks	6	4	3	5	2	7	1
PATH							

Figure 1. Plot layout

Data collection

The data that was collected included the following:

(i) Date of treatments administration
(ii) Monthly rainfal data.
(iii) No. of mature nuts harvested per tree.
(iv) Weight of mature nuts harvested per tree

Data Analysis

For data analysis, the numerical scores for each sample parameter were tabulated and subjected to analysis of variance (ANOVA) using the Statistical Analysis for Scientists (SAS) - students version. Where necessary, pairwise combinations were carried out to determine the level of significance. Data for each season was reported separately especially for those parameters which showed significant differences.

Results and discussion

Rainfall received and its distribution

During the year 2016, the centre and its surrounding areas did not receive good rains. The rains were received during the month of April as expected and continued until June but there was a sharp decrease from May to June and July. Thereafter, no significant amounts were received in the subsequent months. In October there were completely no rains yet that was to be the start of the short rains. This situation severely affected crop production in the whole of coastal Kenya. In some areas like Kinango sub-county in Kwale County, Ganze sub-county of Kilifi County and most parts of Tana-River County; the situation was worse to the extent that the drought affected both humans and livestock. The centre recorded rainfall amount totaling to 654.4mm compared to 757.5mm the previous year. The rains were also characterised by poor distribution especially during those months when the rains were expected in the area. The monthly average rainfall was about 54.5 mm compared to 63.13 mm in the previous year. Most of the rains during the long rains season were experienced between March and May. The short rains were very erratic and did not come as expected.

The only dry months were January to March and again in October (Figure 2). The short rains were also characterised by the effects of la nina and were lower than normal. In that regard, the coconut trees were slightly affected by the drought. However, due to the water harvesting and moisture conservation technologies that were applied onto the trees, they were not severely affected as compared to other similar plantations in the neighbourhood. No trees were lost and again some coconuts were harvested during that challenging period.

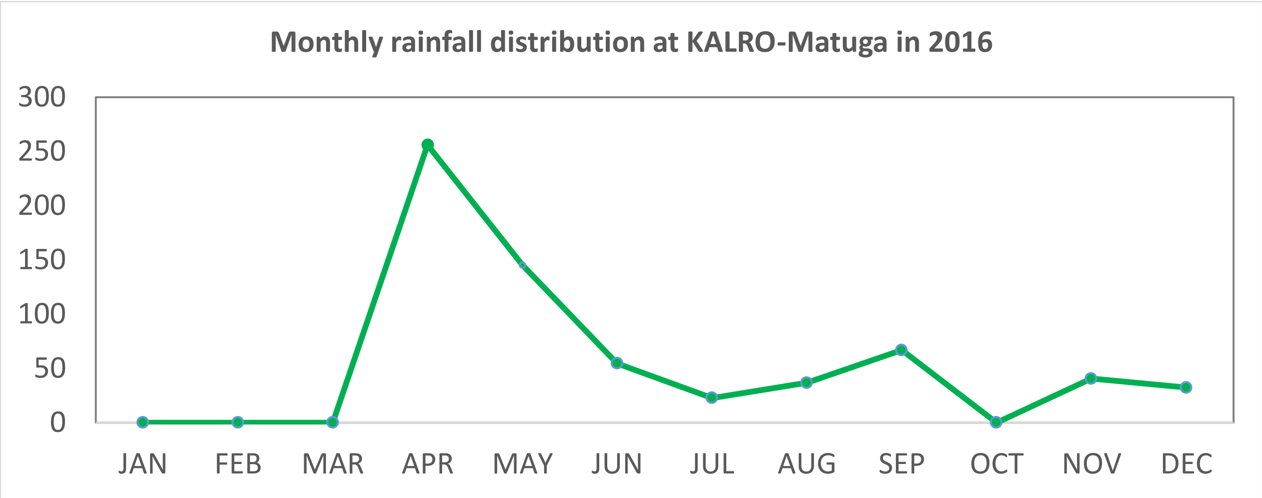

Figure 2. Rainfall amounts and its distribution at KALRO-Matuga

Average number of nuts harvested in the different treatments

The number of coconuts that were harvested in the treatment of ‘water harvesting plus green manure incorporation’ was significantly different ($P<0.05$) betweenthe treatments for water harvesting plus coconut husks buried, water harvesting plus dry grass, water harvesting plus DAP fertilizer and the no water harvesting & no water conservation (control) practice. However, there were no significant differences ($P>0.05$) between water harvesting plus green manure incorporation’ and the water harvesting plus coconut husks on surface treatments (Table 2).

Table 2. Averege number of nuts harvested in different treatments

Treatment No.	Treatment Description	Average number of harvested nuts
1	Water harvesting plus coconut husks on surface	16
2	Water harvesting plus dry grass	**7**
3	Water harvesting plus coconut husks buried	6.3
4	Water harvesting plus farmyard manure	18.6
5	Water harvesting plus DAP fertilizer	9
6	Water harvesting plus Green manure	**22.7**
7	No Water harvesting & no water conservation Practice	7

Increase of nut yield might be due to more availability of nitrogen to the coconut trees that was released by the incorporation of green manure and due to other beneficial effects of Green Manure. Green manure helps to improve the fertility of soil in organic and conventional plant production where animal manure is not used or is used in limited quantities. Green manure crops provide a significant increase in the N supply for the succeeding crop without any yield loss of the main crop compared to the unfertilised variant (N0). This could also be true for the case of Farm Yard Manure application (Figure3).

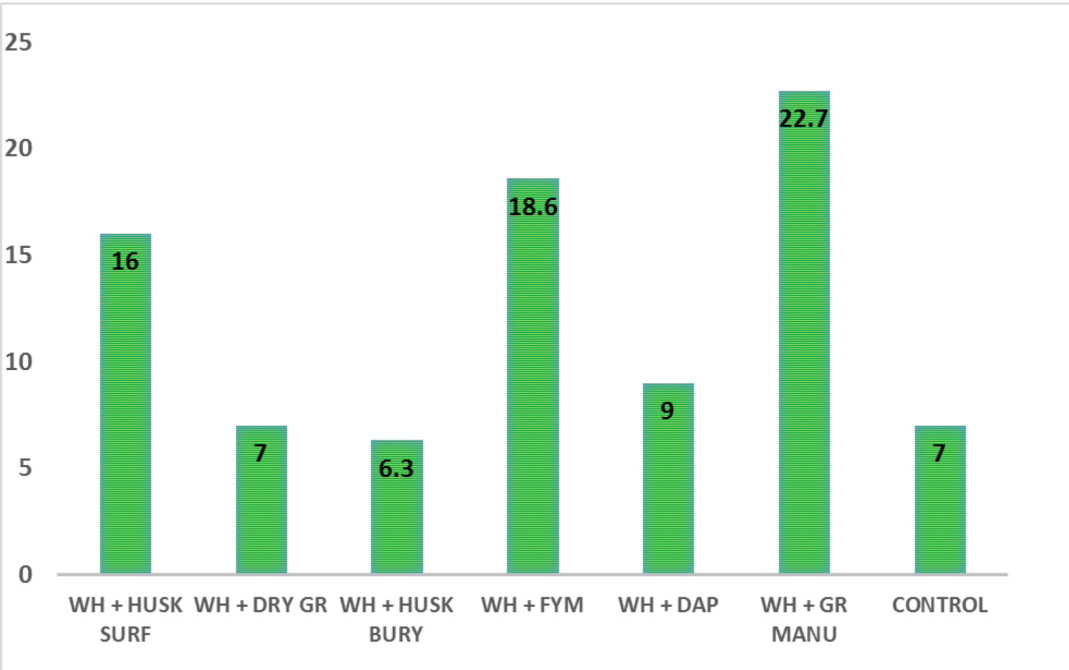

Figure 3. Average number of nuts per treatment

Weight of nuts harvested in the different treatments

The results indicated that the weight of coconuts that were harvested in the treatment of 'water harvesting plus farmyard manure incorporation' was significantly different ($P<0.05$) betweenthe treatments for water harvesting plus coconut husks buried, water harvesting plus dry grass, water harvesting plus DAP fertilizer and the no water harvesting & no water conservation (control) practice. However, there were no significant differences ($P>0.05$) between water harvesting plus green manure incorporation' and the water harvesting plus coconut husks on surface treatments (Table 3).

Table 3. Averege weights of nuts from the different treatments

Treatment No.	Treatment Description	Average weight of harvested nuts (kgs)
1	Water harvesting plus coconut husks on surface	**15.13**
2	Water harvesting plus dry grass	10.77
3	Water harvesting plus coconut husks buried	9.43
4	Water harvesting plus farmyard manure	**18.43**
5	Water harvesting plus DAP fertilizer	10.13
6	Water harvesting plus Green manure	**17.17**
7	No Water harvesting & no water conservation Practice	9.73

Organic manure plays an important role in improving soil permeability to air and water and water stable aggregates. Thus application of organic materials such as farmyard manure considerably improves soil physical properties and nutrient uptake resulting in greater growth, yield and yield components (Singh, *et.al*; 1994, Pandey, *et.al*; 1999 and Mondal and Chettri, 1998). The addition of farmyard manure increased the water holding capacity and reduced the incidence of erosion thereby making more nutrients available to the soil (Costa, *et al*., 1991). This therefore led to the increased weights of the nuts (Figure 4).

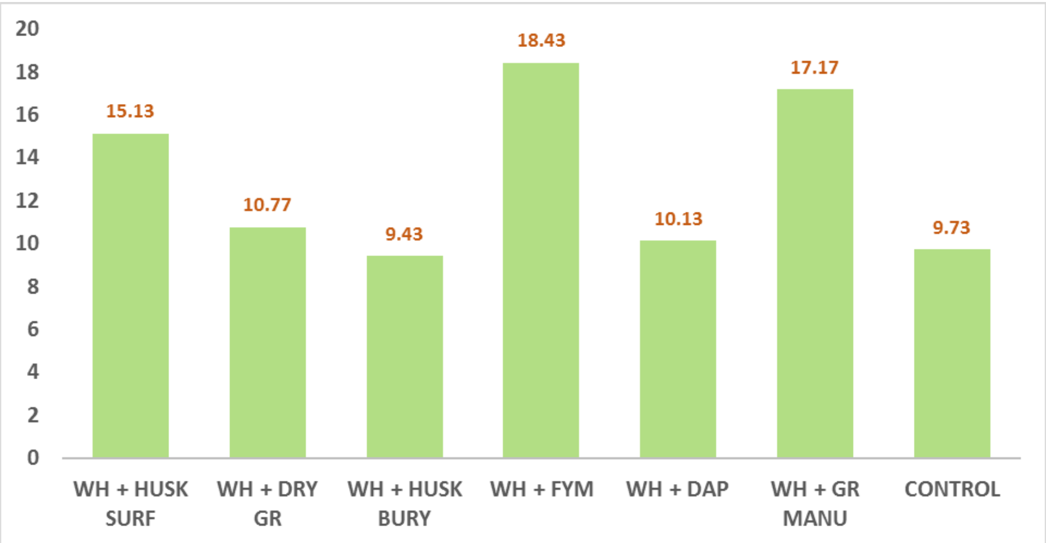

Figure 4. Averege weights of nuts from the different treatments

The weight of nuts increased with the number of coconuts. However, it is interesting to note that the number of nuts and the resultant weight in the treatment where water harvesting was incorporated with farm yard manure was directly proportional (Figure 5). This implies that the nuts harvested were uniform in size. Consumers of coconuts in most cases require nuts of a particular size. As such, this feature could be used as a marketing tool for coconuts.

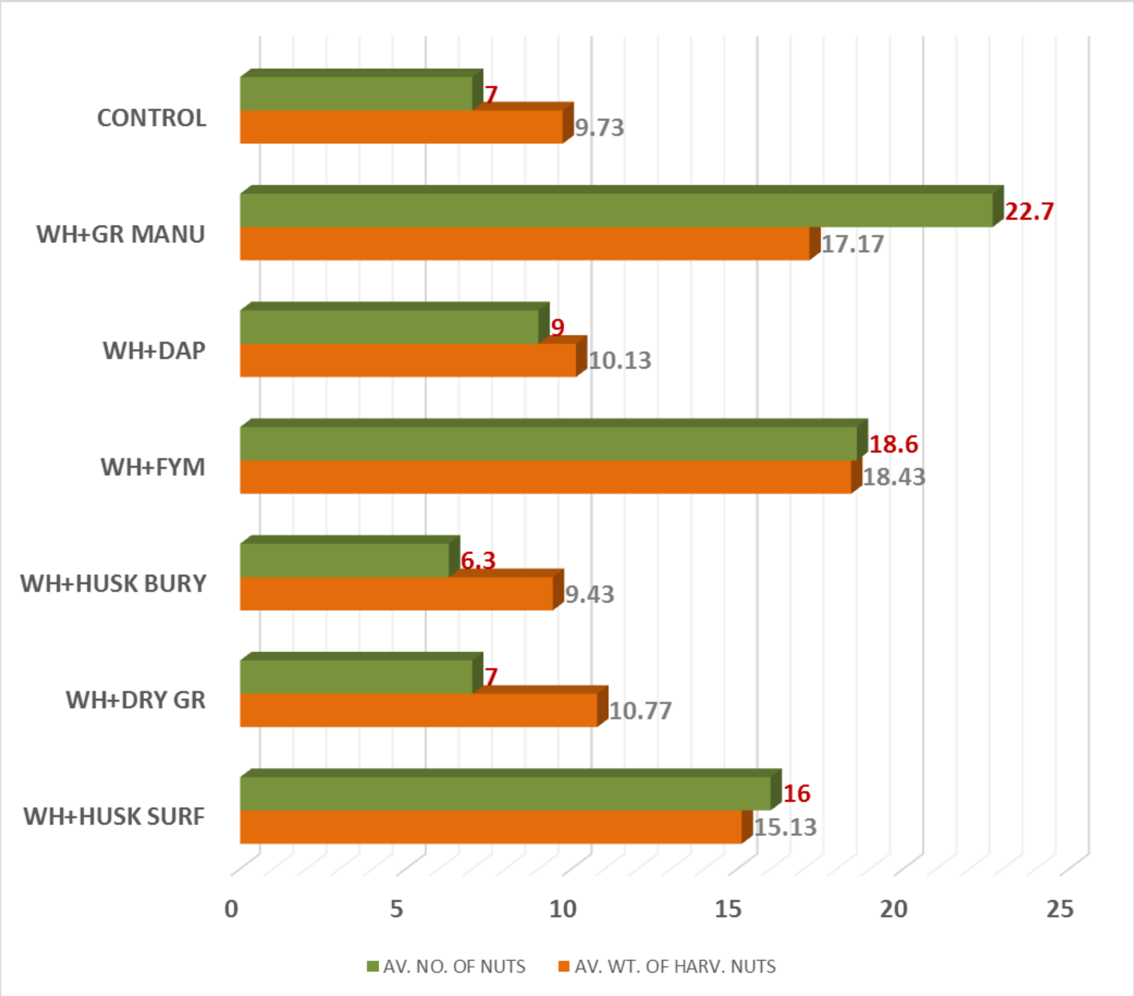

Figure 5. Comparison of the number of nuts and their resultant weights in the different treatments

Conclusion

The study revealed that water harvesting structures and application of the water conservation technologies improves the water retention capacities and hence prolong the availability of moisture for the coconut trees. The treatments of water harvesting and application of farm yard manure together with that of green manure incorporation increased the nut yields. The number of nuts and their resultant weights in the treatment of water harvesting and manure application was directly proportional.

Recommendations

Owing to the potentiality in yields that was demonstrated by the two treatmentsof water harvesting and the application of farm yard manure together with that of green manure incorporation, it is recommended that they be evaluated on-farm in the diverse agro-ecological zones of coastal Kenya to determine their suitability and adaptation.

Acknowledgements

The author would like to thank the following people who made it possible for the study to be carried out. Director General, KALRO for his encouragement and support on joint research activities between the Organization and other stakeholders, Centre Director, KALRO-Matuga for his endless support and guidance. Last but not least all the staffs at KALRO- Matuga led by Mr. Rindano Maingu and Mwaivu Sowa for their active participation in the study and hard work which led to the success of the study.

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Linking Different Levels of Forest Degradation to Suitable Forest Restoration Techniques in Selected Forests in Western Kenya

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Abstract

A study was carried out in Kibiri and South Nandi forests in western Kenya to determine forest restoration techniques suitable for different levels of forest degradation. Three forest restoration techniques were tested under different levels of forest degradation, namely: site protection to stimulate natural regeneration, aided forest regeneration and dense planting. The study employed a split-plot design, in which the main plot comprised site protection while the three forest restoration techniques were sub-plots. There was no significant change in woody species richness, stem diameter and tree height in unprotected degraded forest sites. In protected degraded forest sites rich with internal sources of natural forest regrowth, such as a viable soil seed bank, seed producing remnant trees and live stumps, natural regeneration led to significantly higher woody species richness, stem diameter and tree height than aided regeneration and dense planting. Aided forest regeneration relied on framework trees, which created a micro-climate that was suitable for natural regeneration. It was more successful in disturbed forest sites with moderate potential for natural forest regrowth than in open fields with limited sources of natural regeneration. Dense planting created competition among planted trees, which led to rapid canopy closure. It was very successful in open fields with low potential for natural forest recovery. Late secondary pioneers and intermediate successional species tended to perform better than late successional species in aided regeneration and dense planting. Choice of forest restoration technique, species and site protection are important ingredients for successful rehabilitation of degraded forests.

Keywords: Forest restoration, site protection, natural regeneration, aided regeneration, dense planting

Introduction

Forest degradation is a major environmental challenge in most of the developing world (FAO, 2010; Kenya Forest Service, 2010). It has been identified as one of the key drawbacks to attaining environmental resilience, adaptation to climate change, socio-economic growth, employment creation and poverty reduction because of its impact on key sectors of the economy (Rights and Resources Initiative, 2007). In recognition of this, a majority of developing countries have listed the restoration of degraded forests as a priority activity in their national development agenda. In Kenya, the government, through its development blueprint, Vision 2030, has listed the rehabilitation of key forest ecosystems and water towers as one of its development priorities in the 2018 to 2022 medium term development plan

(Republic of Kenya, 2017). The purpose of this initiative is to increase the forest cover in order to secure ecosystem services, biodiversity conservation and wealth creation. However, a majority of forest restoration efforts have not had much success over the past decade. The situation is attributed to poor understanding of appropriate forest restoration needs for different levels of forest degradation (Duncan and Chapman, 2003).

Four levels of forest degradation are recognized, namely: interrupted forest, disturbed forest, open fields and bare soil (Mullah *et al*., 2013). Interrupted forests are sites within old growth primary or secondary forests with huge canopy gaps as a result of selective harvesting of wood that has altered the forest structure, functions and dynamics beyond the short-term resilience of the ecosystem. The tree cover in these sites ranges between 50 and 75 %. They often manifest high vigour for natural recovery. Disturbed forests include areas where the forest cover has been severely reduced by excessive harvesting of wood and/or non-wood forest resources, poor management, repeat incidences of fire, grazing or other disturbances to a degree that delays forest regeneration after abandonment (Bossuyt *et al*. 1999; Verheyen and Hermy, 2001). The tree cover in these sites ranges between 10 and 50 %. Recruitment and regrowth of woody species in these sites are often delayed because of site quality limitations, competition from herbaceous and shrubby life-forms, low species diversity and isolation of the site from potential seed sources. Open fields are sites where the forest cover has been lost through clear felling of trees causing damage to the soil and vegetation to a degree that inhibits or severely delays the recruitment and growth of woody species. These sites are devoid of trees and are dominated by a continuous layer of grass, herbs, scrubs or low shrubs of ≤ 2 m in height. In cases where some vegetation is left in the landscape, the tree cover is normally ≤ 10 %. Bare soil refers to forest land that has been denuded of all forms of vegetation through processes such as fire, landslide, cultivation or extreme exploitation of forest resources. Such sites are prone to soil erosion. Understanding the different levels of forest degradation is important in defining suitable forest restoration techniques.

Several forest restoration techniques have been used to rehabilitate different levels of forest degradation with varying levels of success (Sajise, 2003). These range from passive restoration techniques, such as managed enclosures and liberation thinning, to active restoration methods, such as enrichment planting, closely-spaced planting using a limited numbers of species, dense planting with many woody species and strip planting (Mullah and Otuoma, 2017). The most widely used among these forest restoration methods is a modified form of enrichment planting, which cannot address all forms of forest degradation. In this paper, we present the results of three forest restoration techniques in a disturbed forest site in Kakamega Forest and an open field in South Nandi Forest in western Kenya. The three forest restoration techniques used included site protection using enclosures to stimulate natural forest regrowth, aided regeneration and dense planting. The objective of the study was to link the two levels of forest degradation to the most suitable forest rehabilitation techniques. Findings of the study are expected to assist forest managers and key actors in forest rehabilitation to design and implement successful forest rehabilitation projects.

Materials and Methods

Study sites

The study was carried out in Kibiri Block of Kakamega Forest and Kobujoi Block of South Nandi Forest. Kakamega Forest is a tropical rainforest located in western Kenya between latitudes 0^o 10´ N & 0^o 21´ N and longitudes 34^o 47´ E & 34^o 58´ E at an elevation of 1,550 m to 1,650 m above sea level (Otuoma *et al*., 2016). The area has a hot and wet climate characterized by a mean temperature of 25 ^{o}C and an annual precipitation of 1,500 to2,000 mm with a dry season between December and March (Glenday, 2006; Mitchell and Schaab, 2008). The forest has over 400 plant species (of which about 112 are tree species), over 300 bird species and about seven endemic primate species (Otuoma *et al*., 2014). The forest vegetation of the forest comprises a disturbed primary forest, secondary forests in different stages of succession, mixed indigenous species plantation forests, indigenous and exotic monoculture plantation forests, and both natural and man-made glades (Tsingalia and Kassily, 2009). Closed canopy old-growth natural forest stands are dominated by evergreen tree species such as *Funtumia africana* (Benth.) Stapf, *Strombosia scheffleri* Engl., *Trilepisium madagascariense* DC., *Antiaris toxicaria* Lesch., *Ficus exasperata* Vahl, *Croton megalocarpus* L. and *Celtis gomphophylla* Baker (Glenday, 2006; Lung, 2009). The forest supports an adjoining human population of about 280,000 people who are distributed in surrounding farmlands and urban centres (Otuoma et al., 2014). Some of the resources that they obtain from the forest include fuel wood, timber, construction poles, herbal medicine, fibre, pasture for livestock, indigenous fruits and vegetables (Musila *et al*., 2010).

South Nandi Forest is a tropical afro-montane forest located 0^o 00´ & 0^o 15 ´N and 34^o 45´ & 35^o 07´E (Njunge and Mugo, 2011). It falls in the transition zone between Kakamega rainforest and the eastern part of the Rift Valley at an elevation of 1,700 and 2,000 m above sea level (Tsingalia & Kassily, 2009). The increase in altitude causes a gradual change in species characteristics from tropical rainforest to tropical afro-montane forest (BirdLife International, 2013). The area's mean annual rainfall ranges from 1,600 to 2,000 mm, while the mean temperature is 19 ^{o}C (Jaetzold & Schmidt, 1983). It has a gently undulating terrain underlain by granitic and basement rocks, which weather to give deep, well-drained soils (BirdLife International, 2013). The forest is the upper catchment of Kimondi and Sirua rivers, which merge downstream to form River Yala that drains into Lake Victoria (Mitchell *et al*., 2006). It has over 86 indigenous woody species. The most dominant of these species are *Croton megalocarpus, Tabernaemontana stapfiana, Strombosia scheffleri, Macaranga kilimandscharicum* and *Celtis africana* (Njunge & Mugo, 2011). The Forest is classified as an Important Bird Area with over 60 species of birds (BirdLife International, 2013). According to the 1999 human population census, approximately 371 people per km^2 reside within 3 km from the forest boundary and depend on it for firewood, honey, pasture, construction materials, herbal medicine and indigenous fruits and vegetables (Kenya National Bureau of Statistics, 2011).

Forest restoration techniques

Three forest restoration techniques were employed in rehabilitating disturbed forest sites in Kibiri Block within Kakamega Forest and open fields in Kobujoi Block within South Nandi

Forest, namely: (i) site protection, which entailed erecting enclosures around 2 to 3 ha plots to exclude livestock and other disturbance agents in order to facilitate natural forest regeneration; (ii) aided forest regeneration, which comprised planting sparsely-spaced framework tree species (at 5 m spacing) to nurture natural regrowth by growing above the weed canopy to supress their growth and accelerate natural forest recovery; and (iii) dense planting, which entailed tree planting at relatively close spacing (0.3 m and 1 m spacing). Site protection and aided regeneration were applied in both study sites, while dense planting was applied in South Nandi only.

Study design

The study employed a split-plot experimental design. The main plot was the protected site, which was used to assess the variation in regeneration status between the protected site and the control (unprotected surrounding area). Sub-plots comprised natural regeneration, aided regeneration and dense planting.

Data collection

We collected data using the stratified systematic sampling method. Assessment blocks were delineated by level of site degradation. Line transects were laid across each assessment block. Sample plots were located at 50 m intervals along each transect. Data were collected within the sample plots on woody species types, mean tree height, mean stem DBH and tree canopy height. Data collection was carried out at the beginning of the study to establish baseline site condition and, thereafter, every year for a period of three and four years, in South Nandi and Kibiri, respectively.

Data analysis

The data on woody species richness and abundance, mean stem DBH and mean tree height were subjected to analysis of variance at 5 % significance level in Genstat statistical software version 17. Post-hoc tests were carried out to separate means using the Ryan-Einot-Gabriel-Wesh multiple range test.

Results

Changes in species richness following rehabilitation interventions

In Kibiri Block of Kakamega Forest Ecosystem, woody species richness increased from an average of two at the beginning of rehabilitation interventions to 21 in Year 4 in planted and protected rehabilitation plots. In unplanted and protected plots, it increased from an average of 1.5 in Year Zero to thirty-two in Year 4 (Figure 1). In the unplanted unprotected plot, which was the control, it increased from two to nine during the same period.

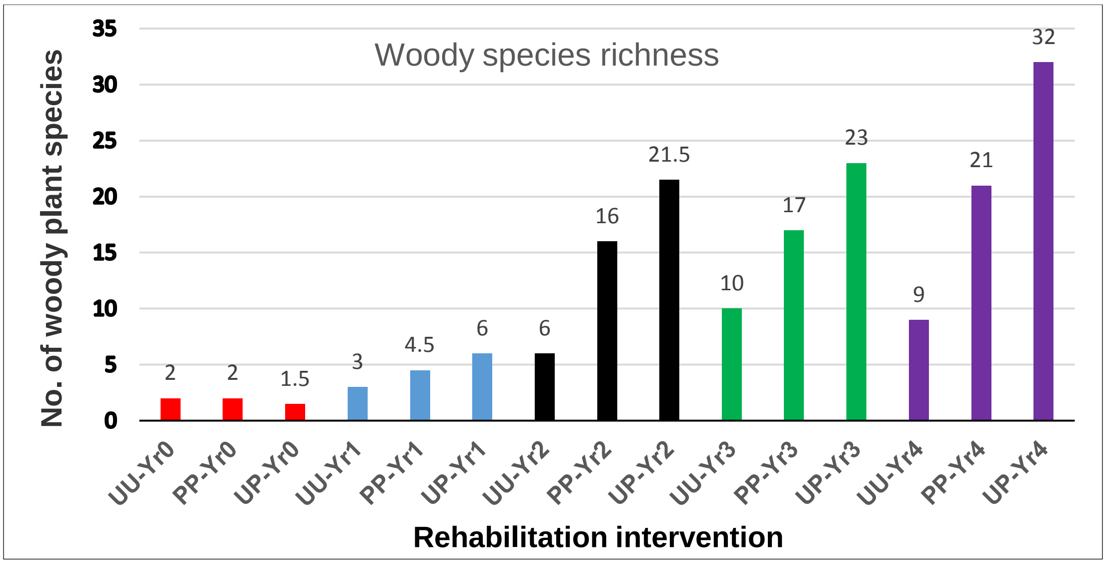

Figure 1. Changes in plant species richness following natural forest rehabilitation interventions in Kibiri Block of Kakamega Forest between 2009 and 2014. UU = unprotected unplanted rehabilitation plots (control), PP = planted and protected rehabilitation plots, and UP = unplanted protected rehabilitation plots.

Changes in woody plant density due to rehabilitation interventions

The number of woody plants in planted protected plots in Kibiri increased from an average of 7.75 plants per ha in Year Zero to 1,544.75 in Year 4. Similarly, the number of woody plants in unplanted protected plots increased from 7.75 to 1,603.2 plants per ha in Year 4. In the unplanted unprotected control plot, the number increased from 40.3 to 201 plants per ha (Figure 2).

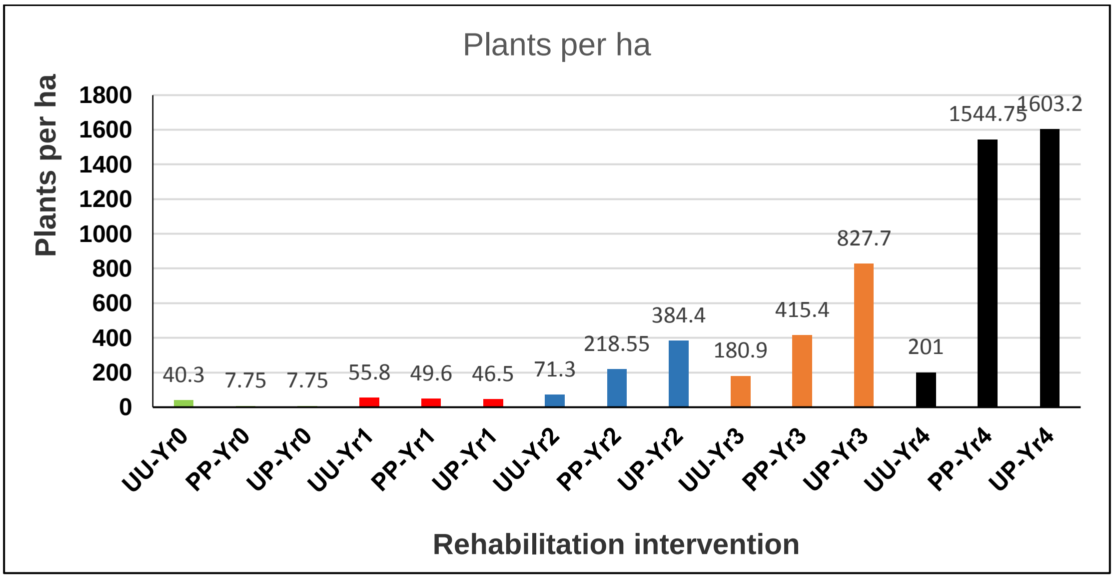

Figure 2. Changes in plant density following natural forest rehabilitation interventions in Kibiri Block of Kakamega Forest between 2009 and 2014. UU = unprotected unplanted rehabilitation plots (control), PP = planted and protected rehabilitation plots, and UP = unplanted protected rehabilitation plots.

Changes in woody stem diameter due to rehabilitation interventions

The stem diameter of woody plants increased from zero in Year Zero to a mean DBH of 5.8 cm in Year 4 in planted protected forest rehabilitation plots in Kibiri. The mean DBH of woody plants in unplanted protected plots increased from Zero to 6.9 cm during the same period. The stem diameter of woody plants in the unplanted unprotected control plot increased from a mean DBH of 2.5 cm to 4.3 cm during the same period (Figure 3).

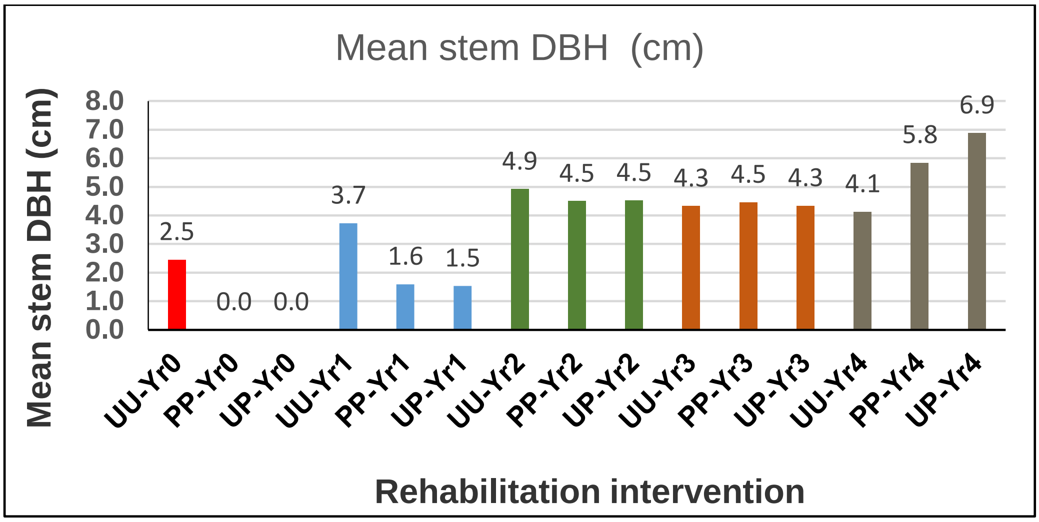

Figure 3. Changes in stem diameter at breast height following natural forest rehabilitation interventions in Kibiri Block of Kakamega Forest between 2009 and 2014. UU = unprotected unplanted rehabilitation plots (control), PP = planted and protected rehabilitation plots, and UP = unplanted protected rehabilitation plots.

Changes in tree canopy height due to rehabilitation interventions

The mean height of tree seedlings in the rehabilitation plots at end of Year Zero was 0.8 m in planted protected plots, which increased to a mean height of 5.1 m by Year 4. In the unplanted protected plots, the mean seedling height was 0.9 m at the end of Year Zero and it increased to 4.1 m by Year 4. In the unplanted unprotected control plot, the mean sapling height was 1.4 m at Year Zero and it increased to 3.5 m by Year 4 (Figure 4).

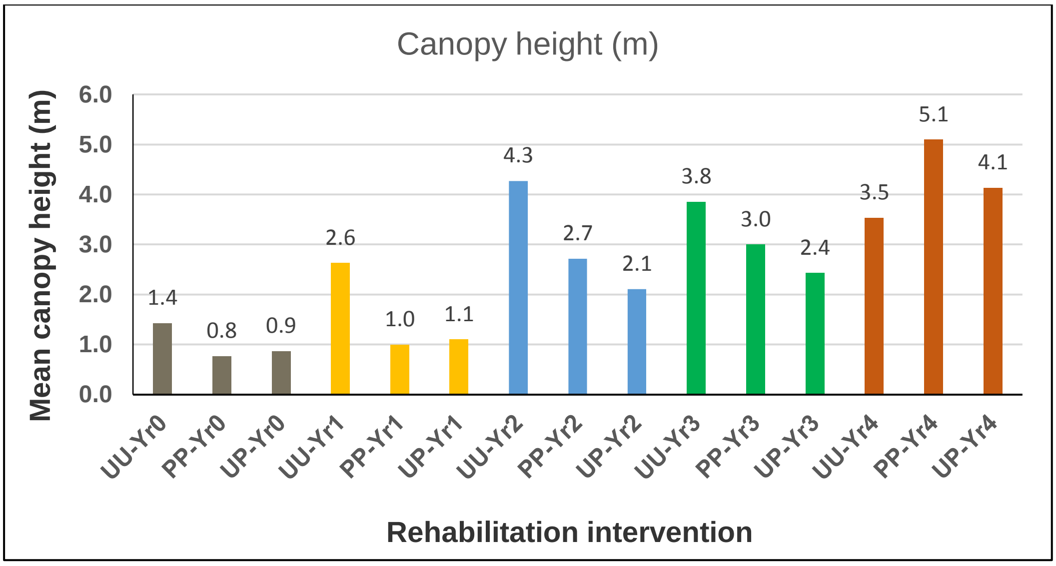

Figure 4. Changes in tree canopy height following natural forest rehabilitation interventions in Kibiri Block of Kakamega Forest between 2009 and 2014. UU = unprotected unplanted rehabilitation plots (control), PP = planted and protected rehabilitation plots, and UP = unplanted protected rehabilitation plots.

Rehabilitation outcomes under dense planting, aided regeneration and natural growth

Changes in woody species richness

There were no changes in woody species richness in the dense planting plots of 0.3 m and 1 m spacing between Year 1 and Year 3 in South Nandi rehabilitation site. The species richness remained at 11, which basically represented the woody plants used for forest rehabilitation (Figure 5). There was a gradual increase in woody species richness under aided forest regeneration. The number of species increased from 11, which were planted in Year Zero to 13 in Year 1 and eventually to 19 in Year 3. In the natural forest regeneration plots, the number of woody species increased from zero at the commencement of rehabilitation interventions to 36 in Year 1 before declining to 24 in Year 3 (Figure 5).

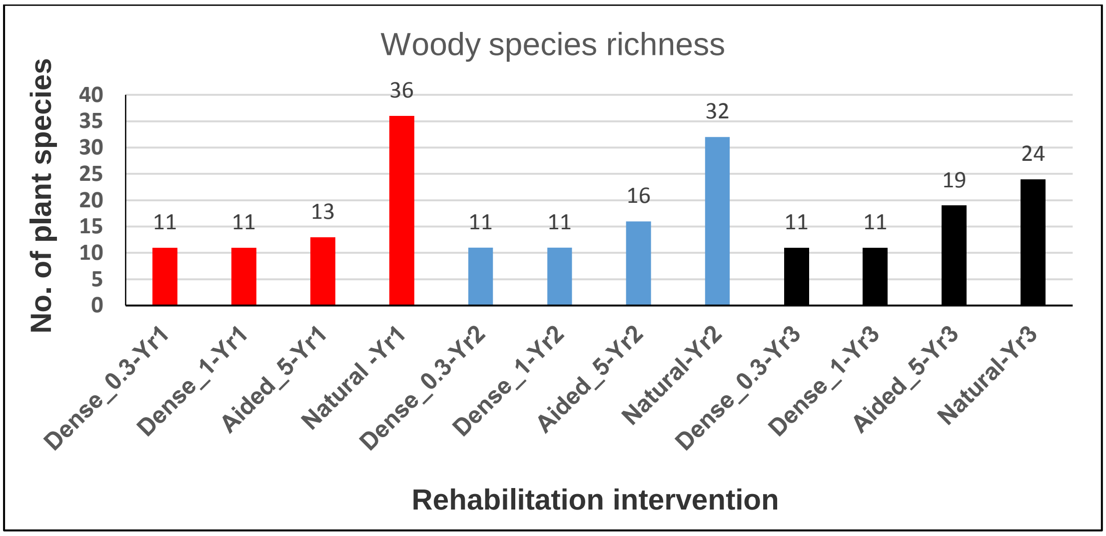

Figure 5. Changes in woody species richness under forest rehabilitation interventions targeting dense planting (0.3 m and 1 m spacing), aided regeneration (5 m spacing)

and natural regrowth in South Nandi Forest between 2010 and 2014. Planted _0.3 = dense planting at 0.3 m spacing; Planted _1 = dense planting at 1 m spacing; Planted_5 = aided regeneration at 5 m spacing; and Natural = natural regeneration.

Changes in stem diameter

The mean stem DBH increased from zero in Year Zero to 1.5 cm in Year 1 and eventually to 3.0 cm in Year 3 under dense planting at 0.3 m spacing. The same increased from zero in Year 1 to 2.4 cm in Year 3 under dense panting at 1 m spacing (Figure 6). Under aided regeneration at 5 m spacing, the mean stem DBH increased from zero in Year 1 to 1.5 cm in Year 3. The mean stem DBH increased from zero in Year Zero to 2.9 cm in Year1 and eventually to 3.4 cm in Year 3.

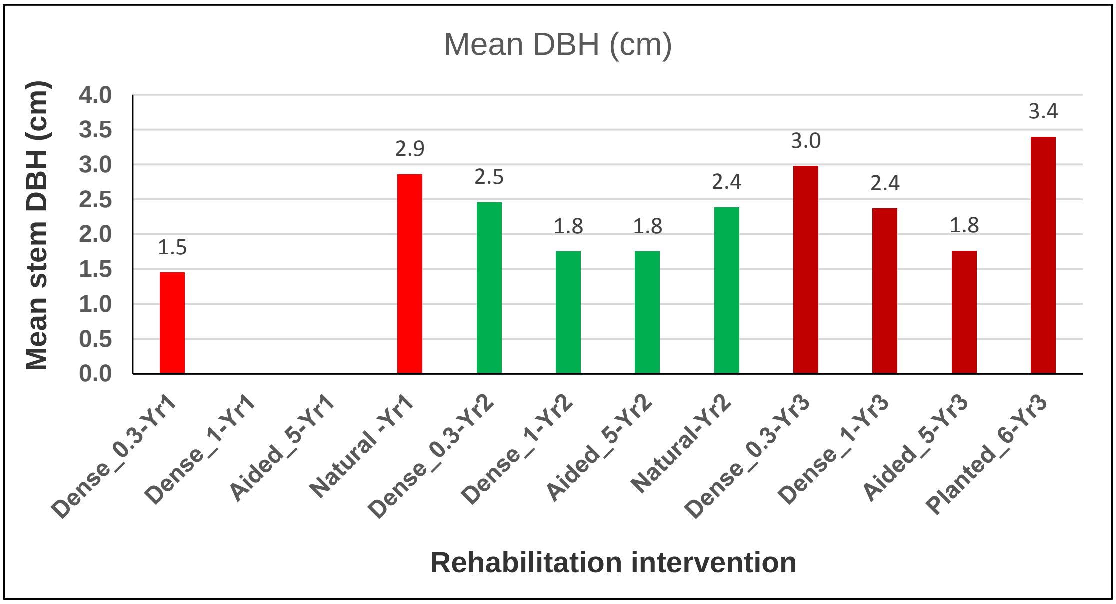

Figure 6. Changes in stem diameter at breast height under forest rehabilitation interventions targeting dense planting (0.3 m and 1 m spacing), aided regeneration (5 m spacing) and natural regrowth in South Nandi Forest between 2010 and 2014. Planted _0.3 = dense planting at 0.3 m spacing; Planted _1 = dense planting at 1 m spacing; Planted_5 = aided regeneration at 5 m spacing; and Natural = natural regeneration.

Changes in tree canopy

The canopy height of saplings increased from 1.4 m in Year 1 to 3.6 m in Year 3 under dense planting at 0.3 m spacing (Figure 7). It increased from 0.6 m in Year 1 to 1.7 m in Year 3 under dense planting at 1 m spacing. Under aided regeneration at 5 m spacing, the height of saplings increased from 0.5 m in Year 1 to 1.6 m in Year 3. The same increased from 1.8 m in Year 1 to 3.4 m in Year 3 under natural forest regrowth.

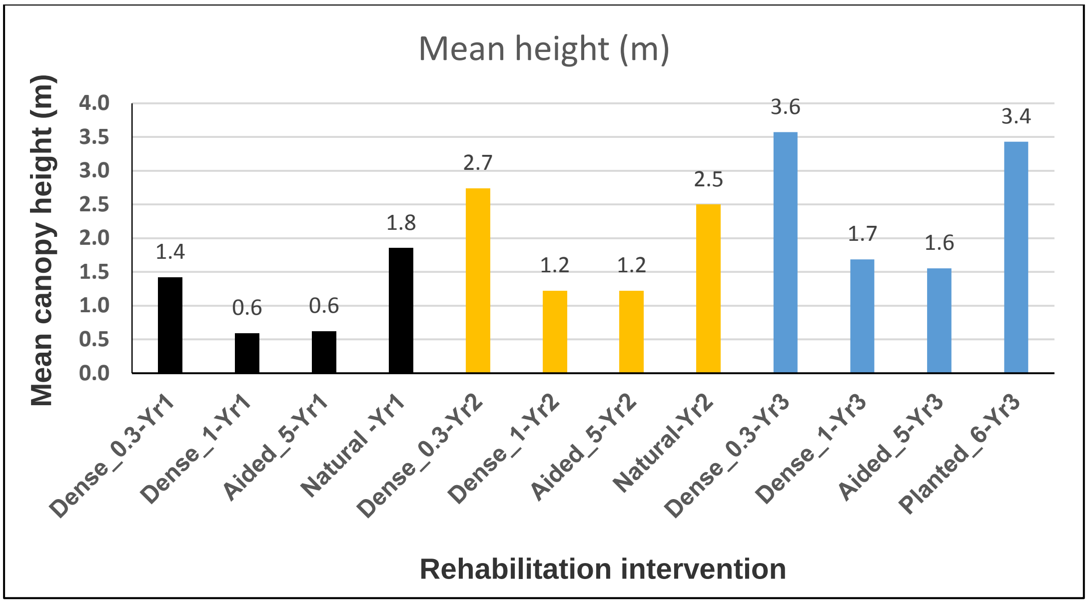

Figure 7. Changes in mean canopy height following forest rehabilitation intervention in South Nandi Forest between 2010 and 2014. Planted _0.3 = dense planting at 0.3 m spacing; Planted _1 = dense planting at 1 m spacing; Planted_5 = aided regeneration at 5 m spacing; and Natural = natural regeneration.

Among the woody plant species that were planted under both aided forest regeneration and dense planting, late successional pioneers and intermediate species, such as *Harungana madagascariensis*, *Celtis africana*, *Croton macrostachyus* and *Bridelia micrantha*, performed better than late successional species.

Discussion

Role of site protection in forest regrowth

The results of this study demonstrate that site protection makes a significant contribution to forest rehabilitation interventions. Both planted and unplanted protected plots recorded high levels of forest regrowth within only three to four years of protection of degraded forest sites. The unprotected control plot at Kibiri recorded some appreciable level of recovery after the implementation of forest rehabilitation interventions in nearby plots. This is suspected to have arisen from the fact that the protected rehabilitation plots were also guarded by community scouts and this may have kept livestock keepers from the general area and in the process spared the control plot from grazing to some extent. Overall, the results suggest that repeat site disturbance, and particularly grazing, is a key impediment to post-disturbance forest regrowth. Grazing in forest ecosystems has been identified as a major impediment to forest regeneration in many countries (Kikoti *et al*., 2015), but it has not received much attention in Kenya. In fact, it is listed as one of the revenue streams from the forestry sector for the Kenya Government. It is not clear, however, how much the country may lose in terms of revenue if a deliberate decision was made to abolish grazing from some forest blocks for a given period of time.

Contribution of natural regeneration to forest recovery

An interesting observation from this study is that some degraded forest sites have the capacity to regenerate naturally without the need for planting. For instance, the results for Kibiri indicated unplanted protected sites had higher woody species richness, stem density, mean stem DBH and mean tree canopy height than the planted protected site. Planted protected sites were expected to have more woody species richness than the unplanted protected sites because the planted seedlings added woody species to it, but this was not the case. As demonstrated by Otuoma *et al*. (2010), the natural regeneration was likely from the soil seed bank, stump sprouts and seed rain from mature remnant trees within the landscape. This illustrates that a natural forest may be degraded, but it retains the capacity to regenerate many years after its degradation. Sites that have lost the soil seed bank and may not have adequate remnant trees may, however, not have the capacity to record a significant level of natural regeneration. Such sites become prime candidates for planting. Thus, natural forest regeneration as a forest restoration technique is more appropriate in rehabilitating interrupted forests and disturbed forest sites with most of their sources of regeneration intact. Depending on the species composition and habitat condition, they require at least 20 years, in the absence of further disturbance, to attain a continuous forest cover.

Forest restoration planting

Two forms of planting were implemented in this study i.e. aided regeneration and dense planting. Aided regeneration was applied in both Kibiri and South Nandi. It appeared to perform better in Kibiri than in South Nandi. This is attributable to the fact that it was basically assisting forest regrowth from the soil seed bank, seed rain and stump routs in Kibiri, unlike in South Nandi where it was applied as a standalone rehabilitation intervention. The results on woody species richness in South Nandi indicated that only a few species emerged in the 5 m planted plot apart from those that were planted. The 0.3 m and 1 m spacing plots did not record any new woody species. The results suggest that the South Nandi rehabilitation site had moderate potential for natural regeneration. This is also explained by the fact that the woody species richness of the plots under natural regeneration declined with time, reducing from 36 in Year 1 to 24 in Year 3. The sparsely spaced planted trees in aided regeneration served as framework trees that nursed newly emerging natural recruits. Thus, aided regeneration as a forest restoration technique can be considered to be more suitable for rehabilitating disturbed forest sites with moderate potential for natural forest regrowth.

Given that woody stems under 0.3 m and 1 m spacing performed better than those under 5 m spacing in canopy height and stem DBH, the results suggest that dense planting is a better rehabilitation technique than aided regeneration in sites with low or no potential for natural regeneration. This is because trees under closer spacing tend to be taller but thinner than those under wider spacing, but this was not found to be the case. They were both taller and larger in DBD. Dense planting is, however, costly in terms of the number of seedlings used and the labour required to plant them and should therefore be avoided in sites with capacity to support natural regeneration. As a forest restoration technique, it is more appropriate in open fields and bare soil. In sites with bare soil, soil conservation structures, such as terraces may be necessary to manage soil erosion.

Conclusion

Degraded forests have failed to regenerate many years after degradation events largely because of repeat incidences of disturbance, such as grazing. Site protection is important for the successful rehabilitation of such sites as a way of excluding agents of disturbance, such as livestock. Natural regeneration remains an important and affordable forest rehabilitation technique. However, it works best in degraded sites that are rich in sources of natural regeneration, such as a viable soil seed bank, mature remnant trees and live stumps. Aided regeneration is suitable for accelerating forest recovery in degraded sites with moderate potential for natural regeneration, such as disturbed forest sites. The sparsely spaced planted trees in aided regeneration serve as framework trees that nurse newly emerging natural recruits. Dense planting is rather expensive because of the number of seedlings used and the labour required in planting, however, it is inevitable in degraded sites with no capacity to support natural regeneration, such as open fields and bare soil.

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The Fate of Taita Hills' Forest Fragments: Evaluation of Forest Cover Change Between 1973 and 2016 Using Landsat Imagery

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Abstract

Landsat images were used to evaluate changes in forest cover of five forest fragments (Chawia, Fururu, Mbololo, Ngangao and Vuria) between 1973 and 2016. The forest fragments are part of the Eastern Arc Mountains, a global biodiversity hotspot that boasts outstanding diversity of flora and fauna and a high level of endemism. Landsat imageries of 1973, 1987, 2001, 2012 and 2016 were analyzed using ArcGIS version 10.0 to provide information on forest cover change of the fragments between 1973 and 2016. Results showed that the annual rate of deforestation was 0.5 % and was similar to global estimates. The forest fragments lost 23.2 % of forest cover between 1973 and 2016. The forest area lost was higher in Vuria (43.0 %) and Chawia (32.7 %) which are non-gazetted forests managed by the County government of Taita Taveta but lower in Fururu (3.2 %), Mbololo (13.7 %) and Ngangao (16.8 %) which are gazetted forests managed by Kenya Forest Service. Fururu and Mbololo forest fragments gazetted slightly over a decade ago suffered less loss in forest cover compared to Ngangao, gazetted much later. Gazettement of forests could preclude further forest degradation and loss by improving their management for effective provision of ecosystem services and conservation of biodiversity.

Keywords: Diversity; Forest cover change; Forest fragmentation; Landsat imagery

Introduction

Tropical forest loss, degradation and fragmentation (Andren, 1994) generate long-term effects on species diversity and composition, community dynamics and ecosystem processes, and is a major cause of biodiversity loss (Achard *et al*., 2002). Socio-economic factors related to rapid human population growth exacerbate the scale of this problem because human population density tends to be positively correlated with areas of high species richness and endemism (Balmford *et al*., 2001). Although large-scale habitat deterioration may affect animal and plant populations in complex and diverse ways, depending on species-specific traits and the temporal and spatial scale of the habitat changes involved, most studies show adverse effects on species richness, diversity, abundance and the composition of flora and fauna (Andren, 1994). To ensure efficacious biodiversity conservation, actions at local scale (within sites) to minimize habitat loss and degradation, should be combined with actions at regional scale (across landscapes) to maximize connectivity, dispersal and gene flow (Lens *et al*., 2002).

Approximately 2.3 million hectares of humid forest at global level are degraded annually due to fragmentation, logging and fires (Lambin *et al*., 2003; Mayaux et al., 2005). Annual deforestation due to fragmentation in the tropical moist deciduous and tropical dry forests is between 2.2 and 0.7 million ha respectively (FAO, 2001; Mayaux *et al*., 2005). In Southeast Asia where forests are under the highest fragmentation pressure, the annual relative rate of deforestation is between 0.8 and 0.9% (FAO, 2001). The annual area deforested in Latin America is large, but the annual relative rate of deforestation is lower (0.4-0.5%). This is due to the vast area covered by the remaining Amazonian forests (FAO, 2001). The African humid forests are receding due to deforestation at a rate similar to that of Latin America (0.4-0.5% per year). The global net loss of forests was alarmingly high between 2000 and 2005 and estimated to be 4.0 million ha per annum (Kelatwang and Garzuglia, 2006). Africa contributes 5.4% to the estimated loss of humid tropical forest cover (Hansen *et al*., 2008).

In Sub-Saharan Africa (SSA), progressive forest loss is at an unprecedented rate of 2.8 million ha annually. This is particularly so in areas with high biodiversity and in Afromontane areas, where the decrease is estimated to be 3.8 % annually (Eva *et al*., 2006). There is growing awareness of the adverse effects of habitat fragmentation on ecosystem functioning (Pellikka *et al.*, 2009) which has resulted into rapid increase in projects and plans to reduce current fragmentation of natural forests (Adriaensen *et al.*, 2003). Moreover, there is increase in application of satellite-based remote sensing methods in evaluating effects of land management (Adriaensen *et al*., 2003; Hansen and Loveland, 2012). Despite the rapid development of remote sensing platforms and tools that allow the integration of detailed geographical information with behavioural properties of focal organisms (Adriaensen *et al.*, 2003), few studies have analyzed spatio-temporal changes in forest cover at ecologically relevant scales, especially in Afromontane forests where biodiversity losses are expected to be the highest (Pellikka *et al.*, 2009).

Like other countries in SSA, Kenya demonstrates ample evidence of the impacts of deforestation on forest ecosystem integrity. Despite their protection status, natural forests in Kenya have lost up to 31 % of forest cover for the last 29 years (Lung and Schaab, 2010). In Taita Hills, substantial forest loss since 1960's is evident in Vuria (99%), Sagala (95%), Chawia (85 %), Ngangao (50 %) and below 50 % for Mbololo (Beentje, 1988). Consequently, the forest fragments of Taita Hills provide exceptional sites to analyze spatio-temporal forest cover change because of various natural or anthropogenic factors. This is because the verdant forest fragments in Taita Hills exhibit exceptionally high degree of endemism and conservation value (Myers *et al.*, 2000; Burgess *et al.*, 2007; Hall *et al.*, 2009). The existing forest fragments have been isolated from one another for over 100 years and are embedded in agricultural landscape and ranked among the most threatened biodiversity hotspot (Newmark, 1998; Pellikka *et al.*, 2009). Currently, indigenous cloud forests cover about 430 ha, reflecting about 98 % forest reduction over the last 200 years (Adriaensen *et al.*, 2003). Despite the small size and fragmented nature of the remaining indigenous cloud forests with over 90 % loss during the last 200 years, Taita Hills continue to boast an outstanding diversity of flora and fauna and very high level of endemism among vertebrates, invertebrates and plants (Beentje, 1988; Pellikka *et al.*, 2009).

Different authors (Beentje, 1988; Wilder *et al.*, 1998; Pellikka *et al.*, 2009) have presented different estimates of the area covered by each of the forest fragment in Taita Hills. However, there is no evidence of comprehensive and systematic attempts to quantify the rate of forest cover change in Taita Hills from the time organized forest management was ushered in by the presidential decree of 1977 banning the cutting of indigenous forests without a license and relate this to the period after the Forests Act of 2005 was enacted and operationalized, to inform policy decisions. The lack of long-term data on forest cover change has been an impediment to forest management and formulation of appropriate policies for enhancing forest conservation. Additionally, several previous mapping efforts have resulted in rather inaccurate areas for the indigenous forest fragments (Beentje, 1988; Wilder *et al.*, 1998). The objective of this study was to quantify forest cover change in Chawia, Fururu, Mbololo, Ngangao and Vuria forest fragments between 1973 and 2016 using Landsat images to provide information on the systematic changes in forest area from the time the presidential ban was effected in order to evaluate the effectiveness of different forest management regimes in reducing deforestation. The selection of the study fragments was justified by their rich floristic and faunistic diversity and the fact that they represent the largest remaining fragments surrounded by cultivated farmlands.

Materials and Methods

Description of the study area

The study was undertaken in five forest fragments (Mbololo, Ngangao, Chawia, Fururu and Vuria) in Taita Hills (3°25'S, 3°820'E), located in Southeast Kenya, 25 km West of Voi town (Figure 1). The forest fragments have similar physical environment, less than 21 km apart and used to have similar plant communities (Pellikka *et al.*, 2009, Omoro et al., 2010). The long rainy season occurs from March to May and a shorter rainy season in November-December, but the mist and cloud precipitation is a year-round phenomenon in the Hills. The average yearly rainfall is 2000 mm (Jaetzold and Schmidt, 1983; Pellikka *et al.*, 2009; Republic of Kenya, 2009). The average temperature is 23ºC with variations between 18ºC and 24.6ºC (Republic of Kenya, 2013). The Hills experience lower temperatures of 18.2ºC compared to the lower zones that have an average temperature of 24.6ºC (Republic of Kenya, 2013). The average relative humidity is 79 and 83% for the lower zones and the Hills respectively (Republic of Kenya, 2013).

Assessment of forest cover change

Landsat images taken in 1973, 1987, 2001, 2012 and 2016 were used because they are readily available, cheap and have suitable spectral and spatial resolutions (Xian *et al.*, 2001; Hansen and Loveland, 2012). Images with less than 10 % cloud cover were selected for periods of interest and analysed to give in-depth insights on the trends in forest cover change due to fragmentation (Sepehry and Jun Liu, 2006; Potapov *et al.*, 2012). Time series analysis of Landsat images considered different intervals between 1973 and 2016. This measure applied due to unavailability of clear satellite images for 10-year interval. Fourteen years interval between 1973 and 2001, 11 years from 2001 to 2012 and 4 years for the period ranging from 2012 to 2016 and the changes in forest cover for 43 years (1973-2016) determined. The rate of forest cover change was also analysed to determine the periodic percentage loss. Additionally, the images were analysed for undisturbed and disturbed sites as well as open grounds created within the forest fragments due to natural phenomena and anthropogenic activities. The year 1973 coincided with uncoordinated forest management activities in Taita Hills. It was not well coordinated and it was until 1977 that well-coordinated forest management started following a Presidential decree banning logging in the forests without a permit (Beentje, 1988).

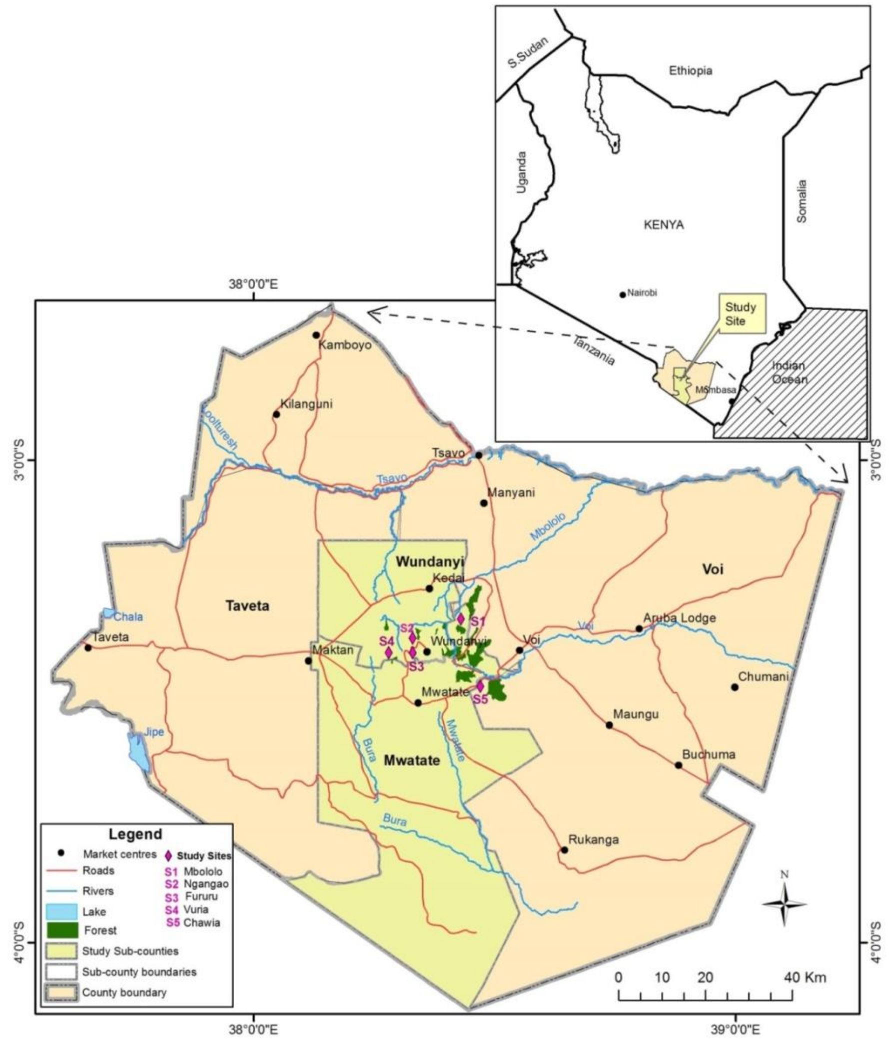


Figure 1. Map of Taita Taveta County showing the study sites

Data analysis

The temporal-spatial change in forest cover was analysed by the real change, percentage change and by trajectory analysis of satellite imageries i.e. by studying the changes occurring from one forest class to another (undisturbed forest, disturbed forest and open ground). Tables and graphs illustrate the synthesized data obtained from the analysis of satellite images.

Results

Forest cover change

The five forest fragments that form a significant part of Taita Hills landscape lost 23.2% between 1973 and 2016 representing a deforestation rate of 0.5% per annum (Table 1). The annual rate of deforestation was highest in Vuria (1.0%) and lowest in Fururu (0.07%). Regarding specific forest fragments, Vuria lost the largest proportion of its forest cover (43.0%) followed by Chawia (32.7%), Ngangao (16.8%), Mbololo (13.7%) and Fururu (3.2%).

Table 1. Forest cover change between 1973 and 2016 of five forest fragments in Taita Hills using Landsat imageries

	Changes in forest cover between 1973 and 2016			
Forest	Area in 1973 (ha)	Area in 2016 (ha)	Loss (ha)	Loss (%)
Chawia	165.6	111.4	54.2	32.7
Fururu	56.9	55.1	1.8	3.2
Mbololo	316.4	273.0	43.5	13.7
Ngangao	252.0	209.6	42.4	16.8
Vuria	211.7	120.7	91.0	43.0
Total	**1,002.6**	**769.8**	**232.9**	**23.2**

Trends in forest cover (area) change between 1973 and 2016

The greatest loss of the forested area in all the five forest fragments occurred between 1973 and 1987 (Figures 2, 3 and 4). During this period, Chawia lost 33.0 % of its forest cover, Fururu (8.7 %), Mbololo (13.2 %), Ngangao (10.5 %) and Vuria (31.6 %). The period after 1987 witnessed reduced loss in forest cover in all the five forest fragments that ranged from 0.3 % to 16.7 %. Moreover, it is worth noting that the forest cover increased in some of the forest fragments between 1987 and 2016. The forest cover increased by 3.3 % in Chawia between 2012 and 2016. Correspondingly, the forested cover in Fururu increased by 9.2 % (2001-2012) and 0.8 % (2012-2016). In the case of Mbololo, an increase of 0.2 % in the forest cover occurred between 2001 and 2012 while in Vuria, the forest cover increased by 4.0 % from 2012 to 2016. However, Ngangao experienced continuous decline in forest cover over the period of the study.

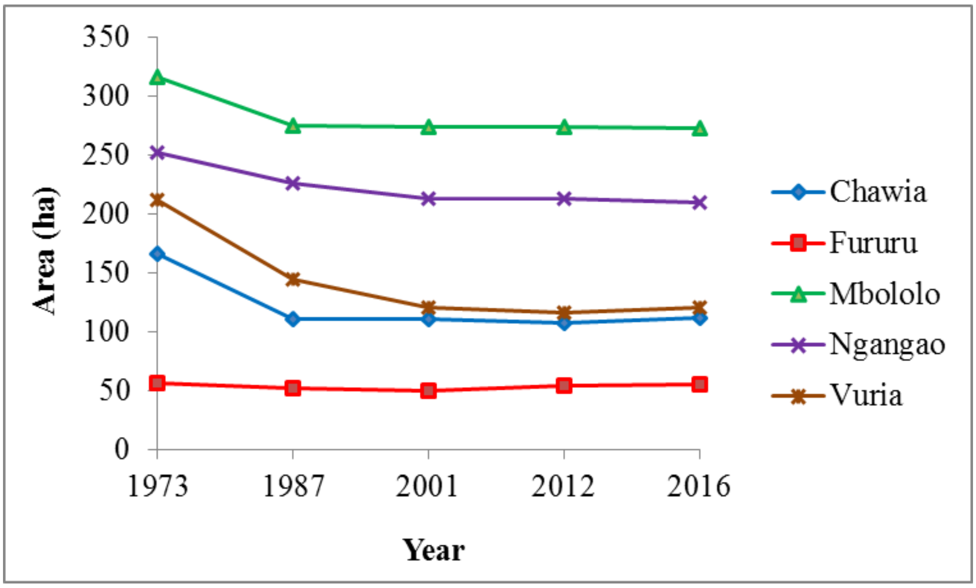
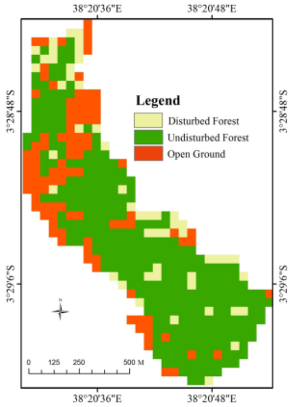
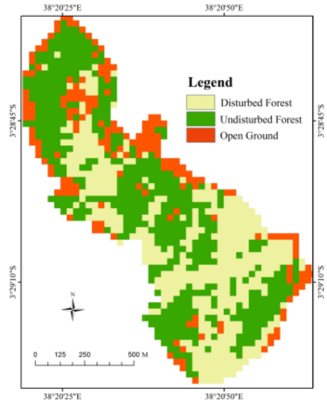


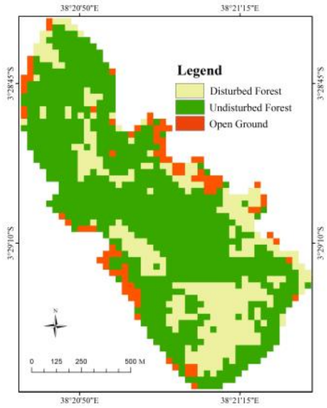
Figure 2. Trends in forest cover change of five forest fragments in Taita Hills between 1973 and 2016 using Landsat imageries



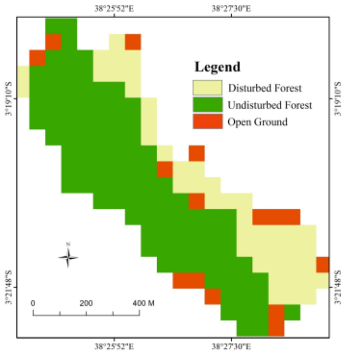
Chawia 1973



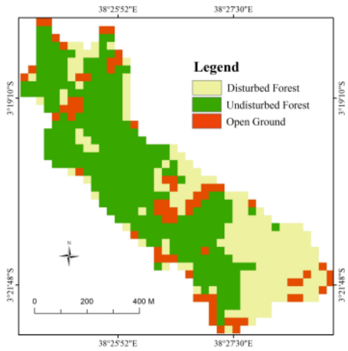
Chawia 1987



Chawia 2016



Fururu 1973



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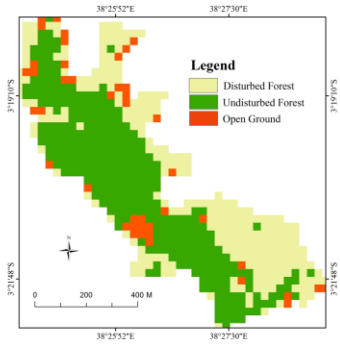
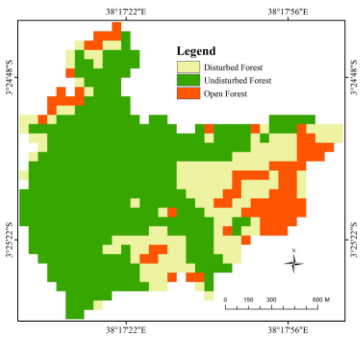
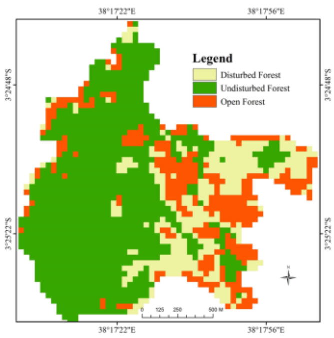


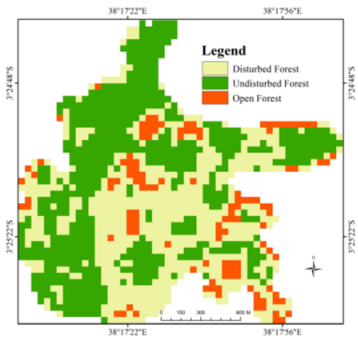
Fururu 2016



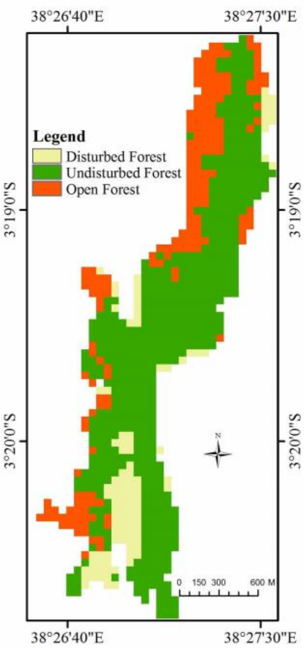
Vuria 1973



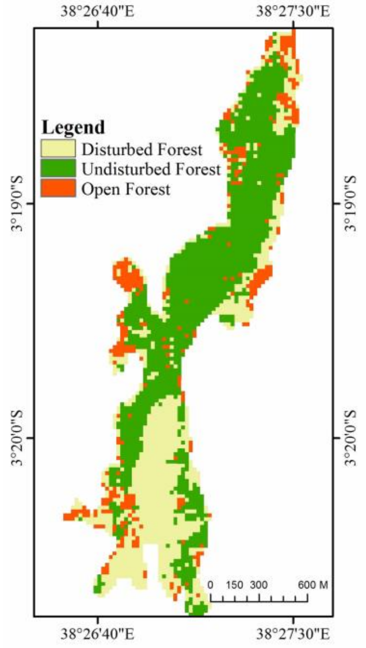
Vuria 1987



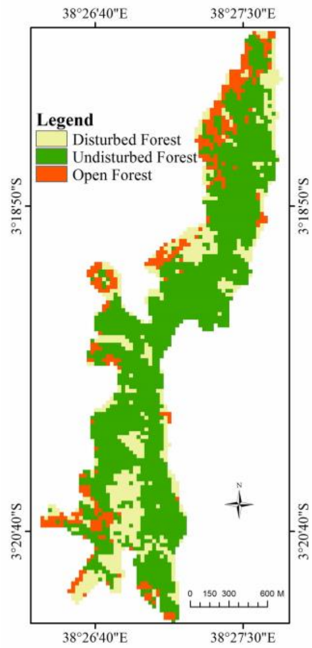
Vuria 2016



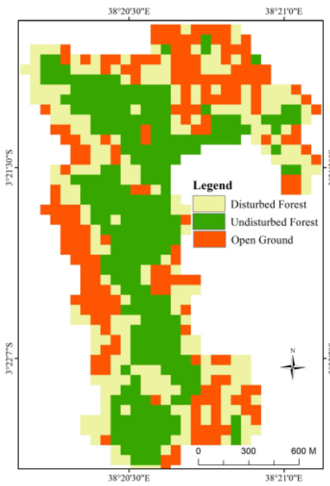
Mbololo 1973



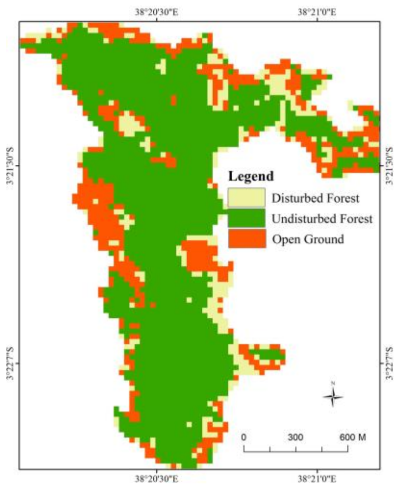
Mbololo 1987



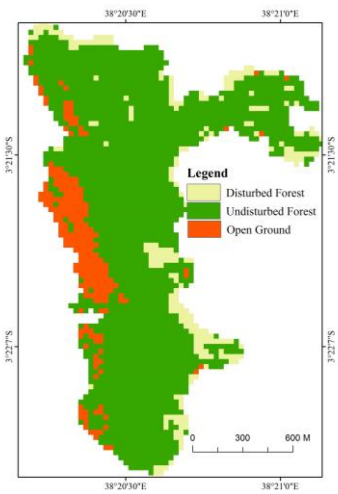
Mbololo 2016



Ngangao 1973



Ngangao 1987



Ngangao 2016

Trends in forest cover change for undisturbed, disturbed and open ground

Trends in forest cover change for undisturbed, disturbed and open ground forest areas varied among the forest fragments (Table 2). The undisturbed forest area in Chawia decreased between 1973 and 1987 before increasing in 2001; but decreased again in 2012 before slightly increasing in 2016. The disturbed forest area increased between 1973 and 1987 before reducing in 2001. From 2001 to 2012, disturbed forest area increased before marginally decreasing in 2016. The open ground declined considerably between 1973 and 2012 followed by a slight increase in 2016.

Table 2. Analysis of forest cover change for undisturbed, disturbed and open ground forest areas of five forest fragments in Taita Hills between 1973 and 2016 using Landsat imageries

		Area (ha)		
Forest fragment	**Year**	**Undisturbed forest**	**Disturbed forest**	**Open ground**
Chawia	1973	111.2	24.1	30.2
	1987	46.0	39.1	25.9
	2001	78.2	20.0	12.2
	2012	70.4	30.8	6.7
	2016	73.9	29.6	7.9
Fururu	1973	35.6	15.8	5.4
	1987	28.4	17.4	6.2
	2001	24.9	15.9	9.2
	2012	33.5	16.3	4.9
	2016	28.6	22.6	3.9
Mbololo	1973	208.4	38.2	69.8
	1987	143.3	97.6	33.8
	2001	143.2	72.1	58.0
	2012	173.0	56.4	44.5
	2016	178.8	61.8	32.3
Ngangao	1973	142.9	37.4	71.6
	1987	154.5	26.7	44.3
	2001	151.9	32.4	29.1
	2012	147.2	48.6	16.9
	2016	144.4	39.5	25.7
Vuria	1973	133.2	50.8	27.7
	1987	87.8	28.7	28.4
	2001	80.3	33.6	6.8
	2012	78.1	26.6	11.3
	2016	56.3	52.8	11.5

In Fururu, undisturbed forest area decreased between 1973 and 2001 before increasing in 2012; but decreased again in 2016. The disturbed forest area increased between 1973 and

1987 but reduced in 2001. The disturbed forest area in Fururu increased between 2012 and 2016. The open ground increased between 1973 and 2001 before decreasing in 2016.

The undisturbed forest area in Mbololo reduced between 1973 and 1987 but increased between 2001 and 2012. The undisturbed forest area in Mbololo increased slightly between 2012 and 2016. From 1973 to 1987, disturbed forest area increased before decreasing between 2001 and 2012 and then slightly increasing in 2016. The open ground decreased between 1973 and 1987 before increasing in 2001. Between 2012 and 2016, the open ground in Mbololo decreased marginally.

Ngangao exhibited a different trend for undisturbed forest area compared to Chawia, Fururu and Mbololo. From 1973 to 1987, the undisturbed forest area increased before plummeting between 2001 and 2016. The disturbed forest area decreased between 1973 and 1987 before increasing in 2001. Between 2001 and 2012, the disturbed forest area increased before plummeting in 2016. A decreasing linear trend in the forest area under open ground was evident from 1973 to 2012.

The undisturbed forest area in Vuria substantially decreased between 1973 and 2016. The disturbed forest area greatly decreased between 1973 and 1987 before slightly increasing in 2001. Between 2001 and 2012, the disturbed forest area reduced slightly before increasing in 2016. The open ground increased marginally between 1973 and 1987 and then plummeted considerably in 2001 before increasing between 2001 and 2016.

Discussion

Forest cover change

The forest loss varied among the forest fragments. The highest forest loss occurred in Vuria and the lowest in Fururu. The variation in the forest cover lost among the forest fragments was due to a number of factors. The legal and administrative status of the forest may have affected the rate of forest loss as well as the forest cover lost. The forest fragments under the management of Kenya Forest Service (KFS) exhibited low rate of forest loss compared to forest fragments managed by the County government. Mbololo, Ngangao and Fururu which are gazetted forests managed by KFS lost the least area compared to Chawia and Vuria which are non-gazetted County forests under the management of Taita Taveta County. In fact, the forest cover loss witnessed in KFS owned and managed forest fragments was less than half of the loss suffered by forest fragments managed by the County government. This is because the County government lacks the technical capacity needed for effective management of the forests under its jurisdiction. Moreover, the number of staff responsible for day-to-day management and conservation of the forests at County level is inadequate; this hinders effective management of the forests on sustainable basis.

The gazettement of the forest fragments and the year of gazettement are important factors that explained the variations in the forest area lost and the associated rate of forest loss for KFS managed forest fragments. Fururu, which was gazetted in 1991, lost only 8.7 % while Ngangao which was gazetted in 2003 lost 10.5 % of its forest cover between 1973 and 1987.

Mbololo which was gazetted in 1991 lost 13.2 % of its forest cover during the same period. However, after the gazettement, the forest loss decreased substantially with Fururu losing 3.6 % of its forest cover between 1987 and 2001. Ngangao and Mbololo lost 5.4 % and 0.5 % respectively between 1987 and 2001. Large forest areas were lost before gazettement but the loss decreased after the gazettement. Vuria, a County forest managed by the County government of Taita Taveta (not gazetted) lost 31.6 % of its forest cover between 1973 and 1987 which was about four times the area Fururu lost during the same period. Moreover, the forest loss in Vuria from 1973 to 1987 was three and two and half times the loss that occurred in Ngangao and Mbololo respectively over the same period.

The annual rate of forest loss was lower in forest fragments that were the first gazetted. Fururu, gazetted 12 years before Ngangao had an annual rate of forest loss of 0.07% that was remarkably lower than 0.4 % witnessed in Ngangao. Chawia and Vuria, not gazetted to date, exhibited annual rate of forest loss of 1.3 % and 2.1 % respectively. Thus, forest fragments not gazetted by KFS and under the management of County government showed high annual rate of forest loss compared to the gazetted forests managed by KFS. The gazettement of forest fragments improved the management of the forests by reducing the rate of forest loss. Therefore, gazettement of forests is fundamental in halting deforestation and for biodiversity conservation.

The largest forest area across the five forest fragments was lost between 1973 and 1987. During this period, Chawia lost 33.0 %, Fururu (8.7 %), Mbololo (13.2 %), Ngangao (10.5 %) and Vuria (31.6 %). This massive loss in forest cover during this period could be attributed to the tragedy of the commons whereby local communities freely extracted materials from the forest fragments in unsustainable manner due to uncoordinated management. Forest management in Taita Hills was not well coordinated from 1973 to 1977 (Beentje, 1988). It was until 1977 that well-coordinated forest management started in Taita Hills following a presidential decree banning logging in the forests without a permit (Beentje, 1988). Besides, the first District Forest Officer (DFO) was posted in Taita Taveta County (formerly Taita Taveta District) in 1982. Prior to the posting, forest management responsibilities in Taita Taveta County were within the domain of Provincial Forest Office in Mombasa. Management of the forests from the Mombasa office was not effective due to the distance and this contributed to poor enforcement that resulted into wanton encroachment of the forest fragments for agriculture and human settlement.

The loss in forest cover of between 3.2 % and 43.0% for the five forest fragments studied compares well with forest cover loss of between 3.8 % and 40.0 % in a period of 50 years previously reported by Eva *et al.* (2006) and Harper *et al.* (2007) for Afromontane forests in Madagascar. Furthermore, related studies on forest cover change using time-series analysis have shown that Kakamega and Nandi forests lost 31.0% of the original area in a period of 29 years (Lung and Schaab, 2010); this compares well with the forest loss of 32.7 % reported in Chawia and the overall average loss for the five forest fragments of 23.2 %. According to Beentje (1988), forest loss in Taita Hills since 1960’s has been substantial. Vuria has lost 99 % since 1960’s, Chawia (85 %), Ngangao (50 %) and below 50 % for Mbololo (Beentje, 1988). The present findings show that since early 1970's, Vuria lost 43.0%, Chawia (32.7 %), Ngangao (16.8 %) and Mbololo (13.7 %). The linear trend in forest cover loss reported by Beentje (1988) is analogous to the trend observed in the current study whereby Vuria lost the largest forest area followed by Chawia, Ngangao and Mbololo. Moreover, the annual deforestation rate of 0.5 % reported in this study is quite similar to annual rate of deforestation in humid tropical forests of Africa of 0.4 - 0.5 % as earlier reported by other authors (FAO, 2001; Hansen *et al.*, 2008).

The areas for the forest fragments are as follows in 2016: Chawia (111.4 ha), Fururu (55.1 ha), Mbololo (273.0 ha), Ngangao (209.6 ha) and Vuria (120.7 ha). The area for Chawia of 111.4 ha reported in this study compares well with 111.3 ha previously reported by Pellikka et al. (2009) but differs from 86.0 ha reported by KFS (2016) and Mbuthia (2003). The present findings on the forest area for Vuria also deviate from earlier reports by Run (1995) and Lanne (2007) of 100.0 ha and 91.0 ha respectively. Preceding studies have estimated the area for Fururu as 14.1 ha (KFS, 2016), 62.1 ha (Pellikka *et al.*, 2009) and 13.0 ha (Mbuthia, 2003). The estimated forest area for Fururu in this study of 55.1 ha compares well with findings of Pellikka *et al.* (2009) but differs from forest area reported by KFS (2016) and Mbuthia (2003). The method of assessment used by KFS is not clearly stated and therefore the difference in the area of Fururu presented in this study and the area reported by KFS for the same forest fragment may be due to the differences in the methods used. The present study estimates the area for Mbololo to be 273.0 ha which is similar to 272.7 ha reported by KFS (2016). Only KFS has quantified the area for Mbololo. Before 2016, the forest area for Mbololo used by KFS for management planning was based on underestimated forest area of 200.0 ha which was 26.7 % less than the actual forest area. This means that KFS has been allocating insufficient human and financial resources for the management and conservation of the forest and hence compromising management effectiveness.

The area for Ngangao (209.6 ha) reported in this study is similar to 206.6 ha previously reported by Pellikka *et al.* (2009) but different from 113.0 ha (Run, 1995), 123.0 ha (Mbuthia, 2003) and 136.0 ha (Adriaensen *et al.*, 2006) and 139.0 ha (Lanne, 2007). This study shows that Vuria had a total forest area of 120.7 ha which is close to 115.0 ha reported by KFS (2016). Prior to this study, only one quantitative study to determine the area for Vuria existed (KFS, 2016). Before KFS and present studies were undertaken, records indicated that the area for Vuria was 1.0 ha (Beentje, 1988). Thus, management decisions for Vuria by forest managers depended on exceedingly underestimated area. Consequently, inadequate resources, both human and financial were made available for management and conservation of Vuria. This partly explains why Vuria has lost the largest forest area for the last 43 years compared to other forest fragments whose estimated areas used in decision making prior to the study carried out by KFS in 2016 were almost similar to KFS estimates of 2016.

There is great similarity in the areas of Chawia, Fururu and Ngangao given by Pellikka *et al.* (2009) and this study. This implies that with proper analysis and interpretation, the use of Landsat images and aerial photographs in quantitative assessment of the changes in forest cover/area provides accurate results that are comparable. On the other hand, there is great variation in the areas of the forest fragments given by other authors with the exception of Pellikka *et al.* (2009) and this could be due to the differences in the analysis and interpretation methods used. Moreover, in the previous studies except Pellikka *et al.* (2009), the methods used are inadequately described and hence unclear and this most likely reduced the accuracy of the results. However, the areas of the forest fragments reported in the present study are accurate and useful for adoption by forest managers and policy makers for making management decisions for sustainable conservation of the forest fragments in order to safeguard the rich flora and fauna diversity found in these forest fragments.

Trends in forest cover change for undisturbed, disturbed and open ground forest areas

The trend analysis in forest cover/area change between 1973 and 2016 for undisturbed, disturbed and open ground areas within the forests showed great variation among the forest fragments studied. In Chawia, the undisturbed forest area decreased between 1973 and 1987. This decrease could be attributed to lack of formal protection of the forest from 1973 to 1977 (Beentje, 1988). During this period, communities entered into the forest without restrictions and extracted wood products hence causing heavy disturbance that resulted into increased areas of disturbed sites within the forest; consequently reducing the area under pristine forest. Between 1987 and 2001, the state of Chawia forest improved following an increase in undisturbed area. This improvement was because of enrichment planting of exotic tree species (*Cuppressus lusitanica*, *Grevillea robusta* and *Eucalyptus* spp) in the disturbed sites within the forest (Pellikka *et al.*, 2009). The reduction in undisturbed forest area between 2001 and 2012 may be due to forest fires that occurred in 2003 and 2006. According to KFS fire incidences records, the estimated combined area burned in Chawia in 2003 and 2006 was approximately 7.0 ha. Occurrence of forest fires is common in Taita Hills' forests during the dry season (December-March) and whenever the fires occur, they are usually very intense and spread quickly due to the presence of dense layer of litter on the forest floors that usually acts as fuel. Over time, the burnt sites within the forest recovered resulting into increased undisturbed forest area between 2012 and 2016. Moreover, rehabilitation of degraded sites in Chawia initiated in 2011 by KEFRI in partnership with a local Community Based Organization, Chawia Environmental Group also contributed to increased area for the undisturbed forest.

The undisturbed forest area decreased substantially in Fururu between 1973 and 1987. Most of the degradation that caused a decline in undisturbed forest area and hence an increase in the area of disturbed sites in the forest probably happened before 1979 when the management of Fururu was not coordinated and there was illicit encroachment for agriculture and human settlement (Pellikka *et al.*, 2009). The slight decrease of undisturbed forest area between 1987 and 2001 and the subsequent increase between 2001 and 2012 may be due to the gazettement of the forest fragment in 1991 that streamlined the management making it effective and the establishment of Eucalyptus plantations on previously bare areas (Pellikka *et al.*, 2009). The decrease in undisturbed forest area observed in 2016 was because of forest fire that occurred in January 2015 destroying an estimated area of 5.0 ha according to KFS fire incidences records.

The undisturbed forest area in Mbololo reduced by 31.3 % between 1973 and 1987 followed a slight increase between 1987 and 2001. As the undisturbed forest area increased, the disturbed forest decreased. Lack of formal protection explains why disturbed areas increased between 1973 and 1987. With the gazettement of Mbololo in 1991, a formal management system was established and this explains the slight improvement in the forest condition between 1987 and 2001. Moreover, due to accessibility challenges, the exotic plantations (*C. lusitanica* and *P. patula*) reflect no symptoms of extraction since they were planted in the late 1980's in areas opened up by illegal logging and this has helped in maintaining the forest in good condition. No fire incidences have occurred in Mbololo in the last 34 years (1982-2016) and this together with the impact of gazettement explains the improved forest condition between 2001 and 2016 as confirmed by the reduction in the areas for disturbed sites and open grounds within the forest fragment.

Ngangao exhibited a different trend in forest cover change for undisturbed forest area. The undisturbed forest increased by 8.1 % between 1973 and 1987 whereas the disturbed forest area decreased by 28.6 % during the same period. Several factors contributed to the increase in the undisturbed forest in Ngangao (1973-1987). Firstly, fast growing succession species like *Phoenix reclinata* and *Dracaena steudneri* var. *kilimanjaro* rapidly colonized the abandoned open areas especially at the top of Ngangao forest closing up the gaps. Secondly, the establishment of exotic plantations of *C. lusitanica* and *P. patula* in mid 1970s in open areas and particularly in the northern part of the forest; these plantations covered previously bare areas resulting into an increase in undisturbed forest area. However, from 1987 to 2016, the undisturbed forest area decreased by 10.2 ha (6.6 %) while the disturbed forest area increased by 12.8 ha (47.8 %). The open ground too increased by 8.8 ha (52.1 %) between 2012 and 2016. This means that the gazettement of Ngangao in 2003 has not had a positive impact on the ecological integrity of the forest. Recurrence of forest fires is responsible for the increase in the areas of disturbed and open ground within the forests. Ngangao has had three incidences of forest fire that destroyed approximately 30.0 ha of the forest. Besides, in 2011, 5.0 ha of Ngangao were lost to forest fire. In early 2016, forest fire burned 6.5 ha of the forest. Although the estimated areas of the forest lost to fires may not be very accurate, they provide a satisfactory explanation why the disturbed and open ground areas have been increasing lately.

In Vuria, the undisturbed forest area greatly declined by 57.7 % between 1973 and 2016. Similarly, the disturbed forest area decreased by 44.1 % between 1973 and 1987 but slightly increased by 18.3 % between 1987 and 2001. Vuria is a County government managed forest and therefore the enforcement of forest protection laws has been rather weak due to lack of capacity by the County government, resulting in subsequent continuous degradation. Uncontrolled grazing of livestock beyond the carrying capacity is also common in the forest. Large numbers of cattle and sheep grazed in the forest fragment all year round. The livestock browses on the vegetation including the regenerates (seedlings and saplings) causing heavy disturbance and hindering the recovery of degraded sites which could have otherwise recovered through natural succession process. At the hill top of Vuria, the forest was cleared for setting up of radio and mobile telephone towers and access road constructed from the edge of the forest to the towers; an action that created perpetual open areas within the forest. Vuria experiences frequent incidences of forest fires. Most of the open and degraded areas within Vuria support a dense matrix of *Blotella cursii*, an invasive fern that dries up during the dry season forming massive fuels and hence increasing the fire risk. According to fire records at KFS Wundanyi station, the latest incident of fire occurred in 2009 and affected approximately 2.5 ha of the forest. The decrease in the undisturbed forest area in Vuria and the accompanying increase in open and disturbed forest areas may be explained by rapid increase in human population, overgrazing, frequent forest fires and ineffectiveness in the management of the forest due to inadequate human and financial capacity of the County government of Taita Taveta.

Conclusion

Gazetted forests managed by Kenya Forest Service exhibited low rate of forest loss compared to County government forests under the management of the County government of Taita Taveta. Moreover, forests that were gazetted earlier, suffered less loss of their cover compared to those that were gazetted much later. Gazettement of forested areas is an effective legal and administrative strategy in the management and conservation of the threatened forest fragments like those of Taita Hills.

Acknowledgments

The authors would like to thank African Forest Forum (AFF) and Kenya Forestry Research Institute through Forest Biodiversity and Environment Management (FB&EM) thematic area for funding this study. Special thanks to Kenya Forest Service, Wundanyi Forest Station for their support during the study. We would also like to thank GIS expert, Geoffrey Maina for undertaking image analysis. Finally, we acknowledge the administrative support received from the Regional Director and Deputy Regional Director, KEFRI Coast Eco-Region Research Programme.

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Land Cover Changes and its Effects on Streamflows in the Malewa River Basin, Kenya

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Abstract

Vegetated landscapes are transformed by both natural and human causes. This is thought to influence river flow regimes. It is argued that restored and reforested landscapes increase stream flow. However, studies done to date have been inconclusive on whether or not trees on restored or reforested landscapes increase stream flow. This study aimed to examine the effects of land cover changes on streamflow of the Malewa River Basin in Kenya. Satellite imagery based spatial change detection using ArcGIS 10.1 and ERDAS IMAGINE software was deployed to estimate the land cover changes. Based on projected land cover change data, a multiple regression technique was used to establish relationship between land cover and streamflow. The results show that at Gauge 2GB01, area under wetland significantly predicted stream flows (b=.134, $t(488)$ =1.978, p=0.049), with an overall model (R^2=0.018, $F(3, 488)$=2.976, p=0.031). Area under grassland (b=.108, $t(488)$=2.325, p=0.02), shrubland (b=.112, $t(488)$=1.976, p=0.049) and amount of rainfall (b=.533, $t(488)$=14.048, p=0.000) combined significantly predicted stream flows. Rainfall alone significantly predicted stream flows (b=.531, $t(488)$=13.885, p=0.000). Overall, the gains in forest restoration did not specifically influence streamflow except in combination with other vegetation and rainfall. There is need to increase soil cover rather than woody biomass alone in the regulation of stream flows. A systematic response to address the drivers of change in land cover is also needed.

Key words: Landscape, Streamflow, Restoration, Land cover.

Introduction

It is not clear how forests contribute to water yield. The lack of clarity is informed by several forest-interactions studies (Silveira *et al.*, 2006; Zhou *et al.*, 2010; Ellison *et al.*, 2012; Beck *et al.*, 2013) under different contexts suggesting inconclusiveness on the relationship between forests and stream flows. It is argued that forests at larger spatial scales contribute to increased evapo-transpiration and precipitation (Ellison *et al.*, 2012). Also, while forests may be net consumers of water and competitors for other downstream users, reduced forest cover could increase stream flows (Price *et al.*, 2010). Generally land use changes and their associated effects are known to impact the hydrology of the catchment area (Bronstert *et al.*, 2002; Foley *et al.*, 2005; Ott and Uhlenbrook, 2004; Tang *et al.*, 2005). Vegetation cover is thought to increase the capacity of catchments, conserve moisture and increase water yield (Lal, 1997). There seems to be a relationship between altered flows and ecological change (Poff *et al.*, 1997); however no evidence existed to show that ecological change was dependent of hydrological change (Poff and Zimmerman, 2010). Surface runoff and river discharge are generally thought to increase with clearance of natural vegetation especially forests. This was evidenced, for example, in the Tocantins River Basin in Brazil (1960-1995) where about 25% recorded increase in river discharge was attributed to expanding agriculture and not a change in precipitation (Costa *et al*., 2003). Elsewhere, stream flows of once degraded areas under large-scale land rehabilitation showed improved base flows (Wilcox and Huang, 2010). On the contrary, findings from 12 meso scale catchments (23 to 346 km^2) in the island of Puerto Rico do not show influence of changes in urban or forest cover on streamflow trends (Beck, 2013).

In the Mara River, Kenya, it was shown that higher flood peaks and faster travel times were experienced in an area that had undergone increased land use pressure (Mutie *et al*., 2006). In the Nzoia river catchment, it has been observed that forests reduce runoff with increased flows in croplands compared to forests. The findings show that as a result of an increase in agricultural area of between 39.6 and 64.3% and reduced forest land from 12.3 to 7.0% (1973 to 2001), runoff increased by 119% (1970 to 1985). The authors noted that climatic factors being constant, land cover changes was responsible for the difference in run-off ranging from 55 to 68% (Githui *et al*., 2009). In another study in this catchment, arising from agricultural expansion, streamflow was found to increase during rainy seasons but decreased during the dry seasons. Streamflow generally increased with increase in forest cover. However when the cover reduced to almost zero, increased peak and mean discharge was noted (Odira *et al*., 2010).

Despite the extensive literature on responses of baseflow and recharge to various human impacts (Price, 2011) these findings are inconclusive. Effects of regenerating forests on stream flow is still little known. This study was designed to address the problem of limited understanding on how forests and trees sustain stream flow in a human modified landscape. It contributes to a body of knowledge on land cover classes – water yield relationships. The objective of this study was to analyse the land cover changes and its effects on streamflows in the Malewa River Basin in Kenya.

Method

Study area

The Malewa River Basin (1,760 km^2) (Figure 1) is located in the Eastern Africa (Gregory) Rift Valley, Kenya. It covers Nakuru and Nyandarua Counties and is administratively bordered by Nyeri and Muranga Counties on the east. The Malewa River discharges about 153 million cubic metres (MCM) per annum (Arwa, 2001). The river has a dendritic drainage system, with several streams (including Turasha, Kitiri, Mkungi, Wanjohi and Malewa) emerging from the upper catchment. Rainfall ranges between 600-1700 mm, with the Kinangop plateau experiencing a yearly rainfall ranging from 1000-1300 mm (Becht & Higgins, 2003). The climatic conditions mirror that of the semi-arid areas, and with bi-modal rainfall distribution: longer rainy season (March to May) and short rainy season (October to November, February, July and December) (Kamoni, 1988). The potential evaporation is about twice the annual rainfall (Farah, 2001). The mean annual temperature ranges between

16^{o}C and 25^{o}C. The daily temperatures range from 5^{o}C to 25^{o}C (Republic of Kenya, 2014). Soils have been influenced by extensive relief variation, volcanic activity and underlying bedrocks (Sombroek *et al.,* 1982); and developed from lacustrine deposits, volcanic and lacustrine-volcanic basements (Girma *et al*., 2001; Nagelhout, 2001). The soils are prone to erosion and compaction (Kiai & Mailu, 1998). Forests and cropland dominates the upper catchment (the Nyandarua range) while livestock grazing is done at the lower catchments (Muthawatta, 2004).

Study design

The study area was sub-divided into three sub-catchments, namely Turasha (Sub-catchment I), Upper Malewa (Sub-catchment II) and Malewa (Sub-catchments II and III combined). Sub-catchment I was mapped to Gauge 2GC04, Sub-catchment II to 2GB0708 and Sub-catchment II and III combined to Gauge 2GB05. The entire basin consisting of the three sub-catchments was mapped to Gauge 2GB01.

Data collection and analysis

Satellite imagery from Landsat MultiSpectral Scanner (MSS) (1973), Landsat Thematic Mapper (TM) (1986) and Enhanced Thematic Mapper Plus (ETM+) (2000) were obtained from the Landsat database (orthorectified archives) (NASA, 2015). These images were geo-processed using ERDAS imagine 2015 and ArcGIS 10.1 software. SPOT image from Astrium was acquired courtesy of WWF Kenya office. UTM Projection Zone 37N and WGS 84 Datum were adopted in the registration procedures. DeltaCue software was used to perform image registration (ERDAS Inc, 2008). Threshold based segmentation technique where a multilevel image is converted into a binary image (Telgad *et al*., 2014) was applied. Image processing and enhancement was done using ERDAS imagine 2015. An object-based classification using a supervised maximum likelihood classification technique was used. A classification scheme based on Anderson *et al*. (1976) was adopted, with six distinct classes generated, namely cropland, forestland, grassland, shrubland; wetland and settlement. Interpreted raster was then converted into polygons using conversion tool in ERDAS imagine. The normalized difference vegetation index (NDVI) algorithm (Rouse *et al*., 1973) was used to detect vegetation health.

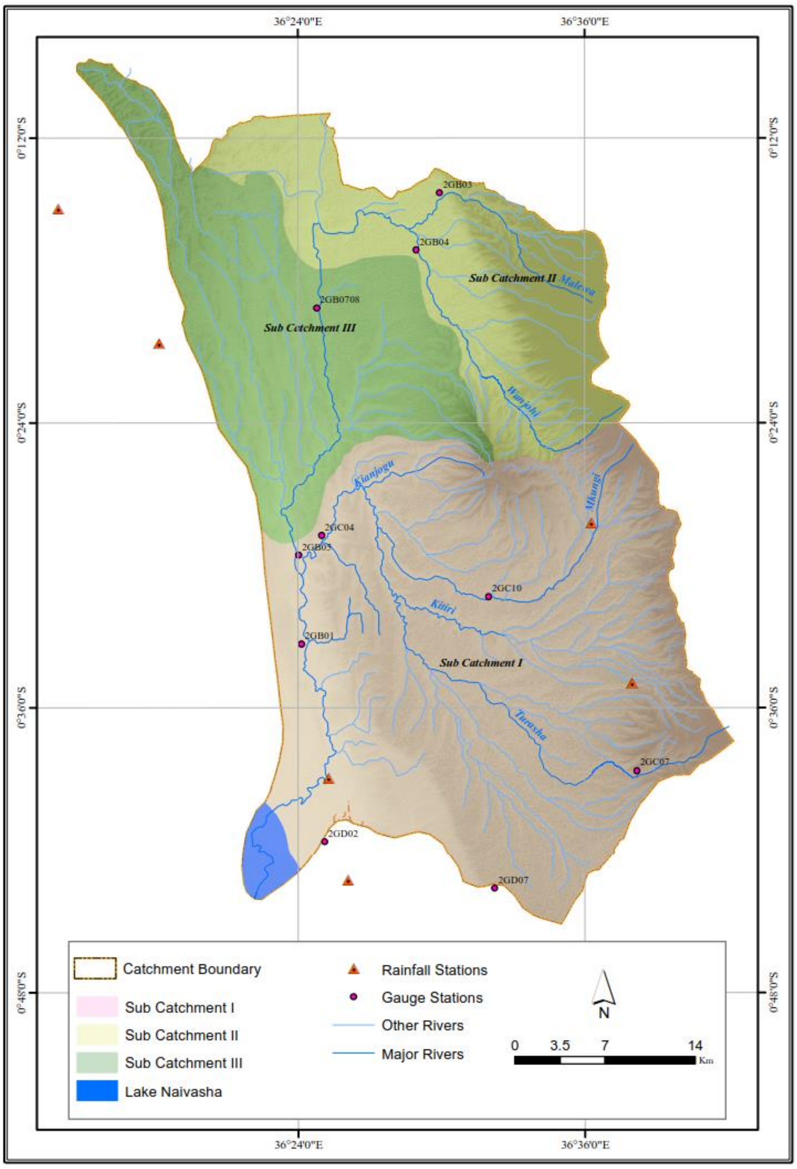

Figure 1. Study area showing location of the gauge and rainfall stations

Daily stream flow data for gauges 2GB01, 2GB05, 2GB0708 and 2GC04 (see Figure 1) was sourced from the Water Resources Management Authority.

Monthly rainfall data for six stations (9036243 - Dundori Forest Station, 9036029 - Kwetu farm, 9036002 - Naivasha Water Bailiff, 9036081 - National Animal Husbandry Resource Centre, Naivasha, 9036025 - North Kinangop Forest Station and 9036241 - Geta Forest Station) was sourced from the Kenya Meteorological Service.

The land cover data generated for the years 1973, 1986, 2000 and 2013 were then projected using polynomial regression with the data fit achieved using a procedure described in Lutus (2013). It was assumed that area under settlement is part of cropland, and so five class projections was applied. The degree of regression was obtained by setting the number of data pairs minus one. The range was limited to 40 years to match with the study timeframe. To reduce possible bias, the polynomial regression order was set to two. Using XLSTAT software (https://www.xlstat.com/), multiple regression technique was run with the projected land cover class and NDVI against streamflow and rainfall data to establish statistical relationships. Regression equations were used to model the relationship between stream flow and the land cover classes (areas under cropland, forestland, grassland, shrubland and wetland) and rainfall amounts at four gauge stations for the years 1973 to 2013. These gauges represent runoff from four delineated catchments and the rainfall amounts assumed to fall in these areas. The significance level was set at 0.05.

The Pearson Product Moment Correlation (PPMC) (*r*) (Pearson, 1948) was used to establish the strength of relationship between any two variables: NDVI, land cover classes, rainfall and stream flows.

Results

Rainfall amounts

The monthly rainfall amounts (1970-2013) ranged between 52mm (2000) and 108mm (1977) with a mean of 80mm. The trend in monthly rainfall is provided in Figure 2.

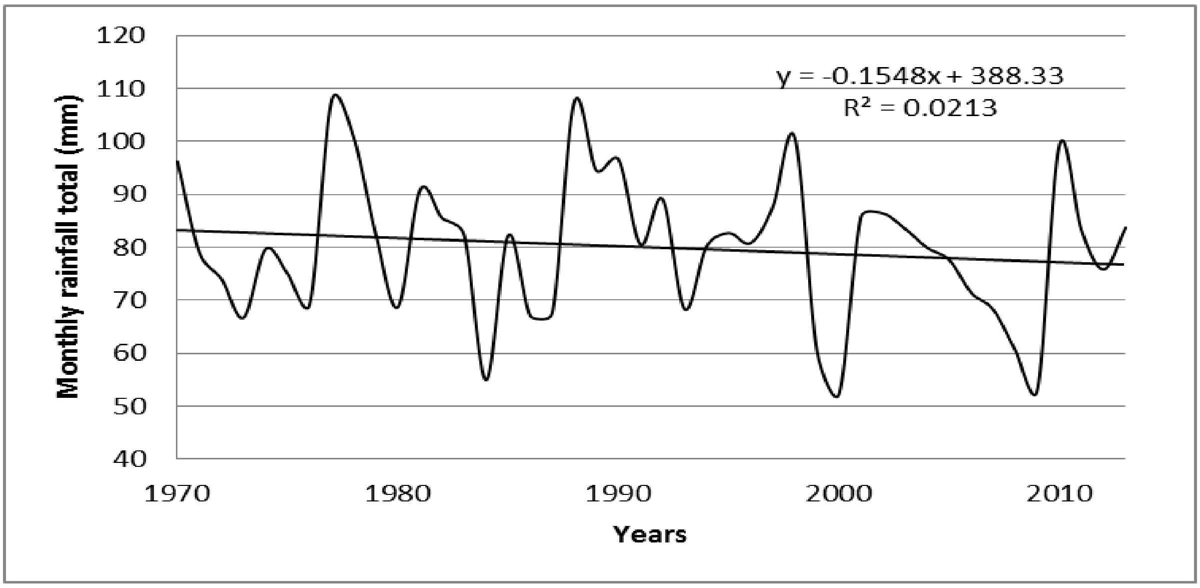

Figure 2. Monthly rainfall trend (1970-2013)

Annual rainfall totals ranged between 627mm (2000) and 1293mm (1977) with an average of 960mm. The annual trend in rainfall amounts is shown in Figure 3.

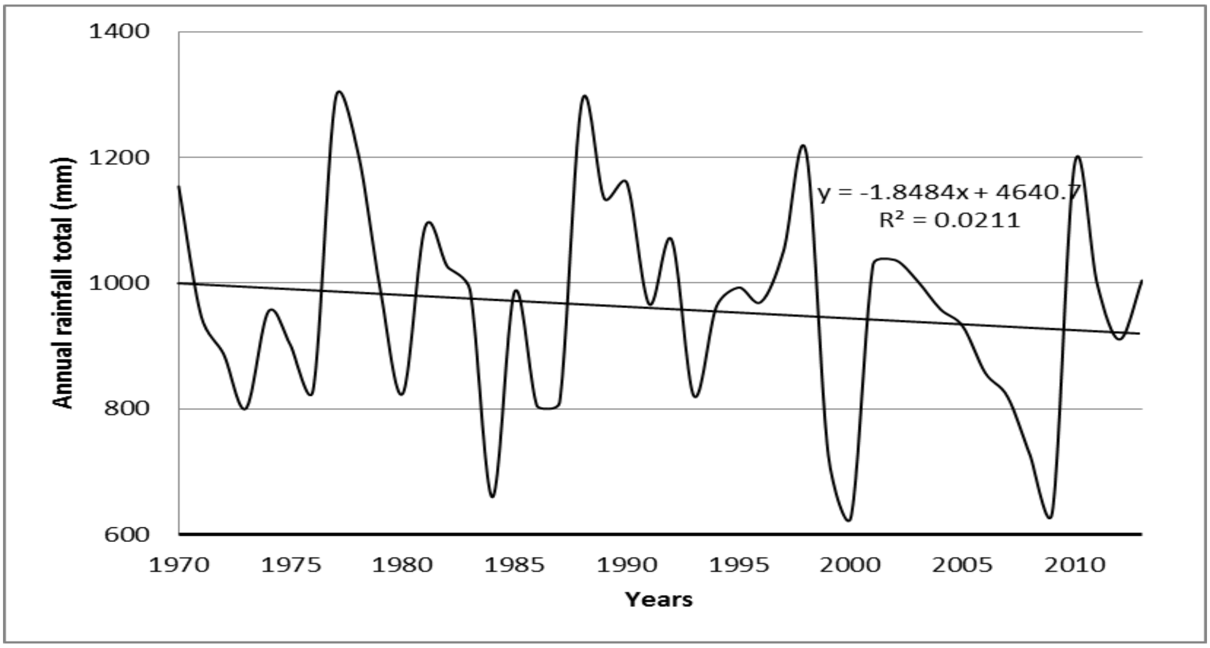

Figure 3. Annual trend in rainfall amounts

Streamflow

On average the Malewa River at gauge 2GB01 discharges (excluding abstractions) about 191 MCM of water annually. There were wide variations in minimum and maximum diurnal and annual flows recorded in all the four gauges. The daily and annual stream volumes and flow for the four gauges stations (1960-2013) are shown below (Table 1).

Table 1. Daily (m^3/s) and Annual (MCM) Discharges at four gauge stations of Malewa Rivers

Gauge	**Mean**		**Minimum**		**Maximum**		**SD**	
	Daily	Annual	Daily	Annual	Daily	Annual	Daily	Annual
2GB01	6.1	191.3	0.3	53.1	139.2	358.6	7.1	74.7
2GB05	3.4	106.4	0.3	28.6	115.4	235.7	5.6	47.0
2GB0708	2.3	70.9	0.00	7.6	144.4	186.1	6.1	45.6
2GC04	4.8	150.4	0.00	38.9	136.7	353.0	8.0	67.2

Notes: Daily data in m^3/s; Annual data in MCM

Spatial extents of the three sub-catchments by cover class

Over the years 1973 to 2013, area under cropland increased by 25,589 ha, forestland 4,295 ha and wetland 687 ha. Shrubland reduced by 28,953 ha and grassland 1,751 ha. The spatial extents of the three sub-catchments and land cover classes for the years assessed are shown in Table 2.

Table 2. Area of sub-catchments by land cover classes and years

Years	Sub-catchments	Area of land cover classes (ha)					
		C	**F**	**G**	**S**	**W**	**Se**
1973	I	54,298	22,901	4,001	18,628	140	
	II	12,541	14,578	1,735	5,302		
	III	21,996	743	3,389	16,165		
		88,835	**38,222**	**9,125**	**40,095**	**140**	
1986	I	55,516	21,663	5,852	16,651	287	
	II	14,853	13,085	3,906	2,282	30	
	III	24,081	823	13,566	3,803	19	
		183,285	**73,793**	**32,449**	**62,831**	**476**	
2000	I	55,626	18,579	1,326	24,182	237	
	II	16,964	14,319	1,390	1,457	11	
	III	30,016	851	1,909	9,459	43	
		102,606	**33,749**	**4,625**	**35,098**	**291**	
2013	I	58,500	24,938	7,183	8,515	812	3
	II	18,467	14,889		772	13	
	III	37,457	2,690	191	1,855	2	83
		114,424	**42,517**	**7,374**	**11,142**	**827**	**86**

Notes: C=Cropland; F=Forestland; G=Grassland; S=Shrubland; W=Wetland; Se=Settlement. Totals are shown in bold text.

Correlation between variables

The Pearson correlation (PPMC) of projected data on the variables: land cover classes, rainfall, NDVI and stream flows are shown in Table 3. The NDVI values had strong negative correlation with crop land (*r*=-0.740, *p*=0.000), a strong positive correlation with grassland (*r*=0.849, *p*=0.000), a moderate positive correlation with forestland (*r*=0.509, *p*=0.000) and a moderate negative correlation with shrubland (*r*=-0.571, *p*=0.000). As the areas under cropland and shrubland increases, NDVI values decrease and vice versa. However, as the area under forestland and grassland increases, the NDVI values also increases. Grassland had strong negative correlation with cropland (*r*=-0.847, *p*=0.000). As area under grassland increases, that of cropland decreases and vice versa. Wetlands had strong positive correlation with cropland (*r*=0.781, *p*=0.000) and a moderate positive correlation with forestland (*r*=0.616, *p*=0.000). Area under wetland increases with increase in cropland and forestland. Shrubland had a moderate negative correlation with forestland (*r*=-0.566, *p*=0.000) and wetlands (*r*=-0.590, *p*=0.000). As the area under shrubland increase that of forestland and wetland decrease and vice versa. A very weak association between forestland and stream flows (*r*=0.098, *p*=0.03), shrubland and streamflow (*r*=0.104, *p*=0.021) and wetlands and streamflow (*r*=0.129, *p*=0.004) was noted. As the areas under forests, shrubland and wetlands increase the magnitude of stream flows also increase. Rainfall and stream flow had moderate positive correlation (*r*=0.531, *p*=0.000). As the amount of rainfall increased, the magnitude of stream flow also increased. NDVI had no correlation with streamflow (*r*=0.014, *p*=0.752).

Table 3. Pearson correlation on the measured variables

	F	R	N	St	C	G	S	W
F	1.000							
R	-.006	1.000						
	(.892)							
N	**.509****	.042	1.000					
	(.000)	(.351)						
St	**.098***	**.531****	.014	1.000				
	(.030)	(.000)	(.752)					
C	**.131****	.014	**-.740****	.078	1.000			
	(.004)	(.752)	(.000)	(.084)				
G	.013	.059	**.849****	-.022	**-.847****	1.000		
	(.770)	(.189)	(.000)	(.629)	(.000)			
S	**-.566****	-.042	**-.571****	**-.104***	-.010	**-.487****	1.000	
	(.000)	(.348)	(.000)	(.021)	(.818)	(.000)		
W	**.616****	-.012	**-.164****	**.129****	**.781****	**-.416****	**-.590****	1.000
	(.000)	(.796)	(.000)	(.004)	(.000)	(.000)	(.000)	

Notes: F=Forest; R=Rainfall; N=NDVI; St=Streamflow; C=Cropland; G=Grassland; S=Shrubland; W=Wetland

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Influences of land cover changes on streamflow

The relationships between stream flows and land cover classes at Gauges 2GB01, 2GB05, 2GB0708 and 2GC04 are presented in Table 4.

Table 4. Stream flow and land cover classes

Gauge	Model	*b*	*SE b*	*β*	*t*	*Sig.*
2GB01	(Constant)	2.276	5.353		.425	.671
	Area under forestland	4.189E-005	.000	.015	.246	.806
	Area under grassland	2.153E-005	.000	.034	.630	.529
	Area under wetland	**.006**	**.003**	**.134**	**1.978**	**.049**
2GB05	(Constant)	5.347	.875		6.110	.000
	Area under grassland	-1.836E-005	.000	-.039	-.855	.393
	Area under shrubland	**.000**	**.000**	**-.115**	**-2.249**	**.025**
	Area under wetland	-.016	.011	-.072	-1.449	.148
2GB0708	(Constant)	1.378	.776		1.776	.076
	Area under grassland	-.001	.001	-.338	-1.378	.169
	Area under shrubland	.000	.000	.067	.620	.536
	Area under wetland	.126	.077	.334	1.638	.102
2GC04	(Constant)	5.347	.875		6.110	.000
	Area under grassland	-1.836E-005	.000	-.039	-.855	.393
	Area under shrubland	**.000**	**.000**	**-.115**	**-2.249**	**.025**
	Area under wetland	-.016	.011	-.072	-1.449	.148

At Gauge 2GB01, area under wetland significantly predicted stream flows (*b*=.134, *t*(488)=1.978, *p*=0.049). Area under wetland explained a significant proportion of variance in streamflow values (R^2 =0.018, *F*(3, 488) =2.976, *p*=0.031. At Gauge 2GB05 area under shrubland was a significant predictor of stream flows (*b*=-.115, *t*(488)=-2.249, *p*=0.025), although the model was insignificant. Area under shrubland at Gauge 2GC04 was a significant predictor of streamflow (*b*=-.115, *t*(488)=-2.249, *p*=0.025), although the model was not significant. The null hypothesis of no significant impacts of the land cover changes on streamflows of the Malewa Rivers was not supported. Significant predictors of stream flows were: areas under wetlands (2GB01) and shrubland (2GB05 and 2GC04).When combined, grassland and rainfall (2GB01); shrubland and rainfall (2GB05); grassland and rainfall (2GC04) were significant predictors of stream flow. Rainfall alone was a significant predictor of streamflow recorded in all the four gauges. There was no evidence to suggest that forest restoration had significant impact on stream flows.

Influence of land cover changes and rainfall on streamflow

The relationship between land cover classes, rainfall and stream flows for the four gauges are shown in Table 5.

Table 5. Stream flow, land cover classes and rainfall

Gauge	Model	b	SE b	β	t	Sig.
2GB01	(Constant)	1.287	6.288		.205	.838
	Area under forestland	.000	.000	.039	.797	.426
	Area under grassland	**-6.958E-005**	**.000**	**-.108**	**-2.325**	**.020**
	Area under shrubland	**.000**	**.000**	**-.112**	**-1.976**	**.049**
	Amount of rainfall	**.063**	**.004**	**.533**	**14.048**	**.000**
2GB05	(Constant)	3.123	.842		3.709	.000
	Area under grassland	-2.794E-005	.000	-.060	-1.409	.159
	Area under shrubland	**.000**	**.000**	**-.103**	**-2.200**	**.028**
	Area under wetland	-.016	.010	-.072	-1.559	.120
	Amount of rainfall	**.027**	**.003**	**.387**	**9.297**	**.000**
2GB0708	(Constant)	-.396	.755		-.524	.601
	Area under grassland	-.001	.001	-.322	-1.406	.160
	Area under shrubland	.000	.000	.061	.601	.548
	Area under wetland	.113	.072	.298	1.565	.118
	Amount of rainfall	.025	**.003**	**.356**	**8.434**	**.000**
2GC04	(Constant)	-.059	.812		-.072	.942
	Area under forestland	.000	.000	.198	1.381	.168
	Area under grassland	.000	**.000**	**-.086**	**-2.036**	**.042**
	Area under wetland	-.006	.006	-.149	-1.064	.288
	Amount of rainfall	.060	**.004**	**.520**	**13.424**	**.000**

At Gauge 2GB01, area under grassland (*b*=-.108, *t*(488)=-2.325, *p*=0.02), shrubland (*b*=-.112, *t*(488)=-1.976, *p*=0.049) and amount of rainfall (*b*=.533, *t*(488)=14.048, *p*=0.000) significantly predicted stream flows. Both area under grassland and shrubland, and rainfall combined explained a significant proportion of variance in stream flow values (R^2=0.301, *F*(487) =52.47, *p*=0.000). At Gauge 2GB05, area under shrubland (*b*=-.103, *t*(488)=-2.200, *p*=0.028) and amount of rainfall (*b*=.387, *t*(488) = 9.297, *p*=0.000) combined significantly predicted stream flows (R^2 =0.160, *F*(4, 487) =23.235, *p*=<0.000). At 2GB0708, the amount of rainfall significantly predicted streamflow (*b*=.356, *t*(487)=8.484, *p*=0.000), with a significant overall model (R^2=0.136, *F*(4,487) =19.215, *p*=0.000). At 2GC04, area under grassland (*b*=-.086, *t*(487)=-2.036, *p*=0.042) and amount of rainfall (*b*=.520, *t*(488)=13.424, *p*=0.000) combined were significant predictors of streamflow (R^2=0.272, *F*(4, 487) =45.535, *p*=0.000).

Influences of rainfall on stream flow

In all the four gauge stations, rainfall when considered alone significantly predicted stream flows (Table 6).

Table 6. Influence of rainfall on streamflow

Gauge	Model	b	SE b	β	t	Sig.
2GB01	(Constant)	1.200	.422		2.840	.005
	Amount of rainfall	**.062**	**.005**	**.531**	**13.885**	**.000**
2GB05	(Constant)	1.200	.277		4.326	.000
	Amount of rainfall	**.027**	**.003**	**.386**	**9.272**	**.000**
2GB0708	(Constant)	.261	.274		.954	.341
	Amount of rainfall	**.025**	**.003**	**.358**	**8.481**	**.000**
2GC04	(Constant)	.121	.419		.289	.773
	Amount of rainfall	**.059**	**.004**	**.514**	**13.279**	**.000**

Discussion

It is demonstrated in this paper that land cover changes had an effect on the quantity of streamflow of the Malewa rivers. Vegetation health was being negatively affected by growth in cropland and demise of shrubland. This however improved when there was growth in areas under grassland and forestland. Changes in grassland affected the intensities of vegetation, and this was influenced by expanding cultivation. It appears that exploitation of wetlands was linked to increase in cropland, implying that much of the land under wetlands was subject to conversion to other uses rather than remained as water masses. Clearance of shrubland was associated with losses of forests and wetlands, and on the contrary, more forests and wetlands were linked to extensive shrubland. Forestland, shrubland and wetlands all were positively associated to streamflow, meaning, aside from rainfall, these three are the determinants of streamflow. However, wetland and shrubland have significant though weak relations to streamflow. In the absence of rainfall, shrubland and grassland significantly influenced streamflow Rainfall had substantial influence on streamflow in all gauges. Surprisingly, NDVI as an indicator of vegetation health did not show any influence on streamflow. These results demonstrate the importance of vegetative cover and not necessarily trees in a landscape. The fact that grassland and shrubland (and to some extent forests) have the ability to increase soil cover means that more water is likely to infiltrate and be retained in the soil sub-surface. Artificial wetlands seems to have been created with conversion to croplands, although forests association with increased wetlands is largely unexplained safe for the notion that water would be discharged slowly to the wetland.

While these findings seem to confirm that of other similar studies it is evident that there are still mixed conclusions. Increased stream discharge and surface runoff has been associated with forest cover loss. An increasing trend in annual discharge of the Nyangores river in the upper Mau region has been attributed to land cover change (97.5 %) and climate change (2.5 %) (Mwangi *et al*., 2016). However a review of 37 catchments in East Africa show that despite the loss in forest cover about 63% of the watersheds had no significant changes in annual discharges while 31% were showing increasing trends. About half of the watersheds did not show trends in wet seasons and low flows. In the contrary 35 % had decreasing trends in low flows. It was also established that forest cover and runoff, mean discharge and peak discharge were weakly correlated. The authors conclude that forest cover alone did not

present an accurate predictor of streamflow in the catchments (Guzha *et al*., 2018). This finding is in line with that from this study. In a similar study in the wider the Lake Naivasha basin, it was noted that due to upstream landscape changes driven mainly by population increase there was an increase in total runoff despite no changes in rainfall. As such, monthly total runoff volumes increased significantly (p <0.01) by up to 32 % (Odongo *et al*., 2014).
As reported in the WeruWeru Kiladeda sub-catchment of the Pangani Basin, following a decrease in forest and agricultural land due to increased urbanization, shrubland and bare land (1990 to 2009), river flow showed a low dry season and peak wet season flows (Chiwa, 2012). Due to deforestation, land fragmentation, cultivation of wetlands and rapid increase in human settlements, streamflow and ground water reduced in the eastern Mau (Kundu et al., 2004). Baseflow was found to decrease due to combined effect of human and natural factors in the River Enjoro catchment (Chemelil, 1995). In the Ewaso Ngiro South River, upper catchment forest cover and the number of rainy days declined while there was a general increase in mean annual rainfall (Kiura, 2009). It has been explained that an increase of shrubland allows less infiltration of water due to crusting of the soil which causes both higher peak flows and an increase in total volume of discharge Cultivated land allows less infiltration than forest, and is often more prone to runoff and overland flow (Gumindonga, 2010).

Conclusions

It is evident that wetlands, shrublands and grasslands played important roles in sustaining streamflow. Wetlands have the ability to slowly release water downstream. Grassland and shrubland increase soil cover therefore water is likely to infiltrate and be retained in the soil sub-surface.
This study recommends the following interventions:

- As rainfall is key to streamflow yield, it is important to manage ecosystem beyond the immediate catchment.
- Manage trends in stream flows by adequate establishing vegetation cover to slow down the flow and increase infiltration. This requires intensifying activities such as planting of grasses, cover crops and woodlots.
- Implement participatory scenario planning to manage different stakeholder expectations on land use. Expansion of cropland and mitigation of losses on shrubland and forests is suggested to intensify sustainable agricultural production through a scheme of optimal land use applying sustainable land use practices such as agroforestry and woodlots that have economic returns to the farmers.
- Further studies are needed to ascertain the quantum contributions of land cover change and climate variables on stream flows at specific restoration sites; and to determine seasonal influence of land cover changes on streamflows.

Acknowledgement
We are grateful to WWF Kenya, Astrium and National Aeronautics and Space Administration for the use of satellite images. Thanks to Water Resources Management Authority and the Kenya Meteorological Service for providing relevant data. Also this work benefitted from the use of ESRI analytical software.

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Destruction of Watershed Forests Beyond Trees: Effects of Anthropogenic Disturbance on Forest Herpetofauna of Cherangani Hills Forest

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Abstract

Human driven disturbance of forests has been well documented in many forests including the Kenyan water towers. Most attention on this disturbance and its effects has however been limited to vegetation, given that the effects to other forms of biodiversity inhabiting these forests have either been poorly documented or too generalized. Given that different groups of biodiversity respond differently to disturbance, such generalizations can misguide conservation. The present study determined the relationship between herpetofauna (reptiles and amphibians) and the agents of disturbance in Cherangani Hills Forest. Time-Limited Searches and pitfall traps were used to sample herpetofauna in forest, wetland, farmland, glade, rocks and scrubland alongside agents of disturbance (logging, grazing, invasive plants, and charcoal burning). Species richness and diversity were determined in ESTIMATE S and the differences in the means compared in STASTICA 8. The distribution of herps and threats were computed in Excel. The relationship between the threats and species diversity and richness was determined through regression. There was a significant difference between herp diversity and at least three agents of disturbance in each habitat type. No relationship was found between the agents of disturbance and herpetofaunal richness (R^2=0.186) but a positive relationship was found between threats and herp diversity (R^2=0.5808). This study indicates the need for timely protection of forests because of the influence they have on the other nested habitats making them suitable for other species. This should be done before the effects of destruction are pose further threats to the species.

Key words: herpetofauna, species diversity, habitat disturbance

Introduction

Human driven disturbance of forests has been well documented in many forests including the Kenyan water towers (Akotsi *et al.,* 2006, 2009). In many cases however, this disturbance and its effects has been limited to vegetation given that the effects on other forms of biodiversity inhabiting these forests has either been poorly documented or too generalized. Consequently, the status of the other forms of biodiversity have been overlooked or given blanket conservation which may not necessarily be effective. Tracking the success of such blanket attention is usually a challenge because the information on what is being conserved can be scanty, inaccurate, or missing in some instances (Crane and Bateson, 2003).

Different forms of biodiversity respond differently to human disturbance (Watson *et al.,* 2005; Wagner and Böhme, 2007) and this information is crucial for any conservation programme. The two extremes of these reactions are not affected to extirpation/extinction. Between these two are adaptation and migrations to other suitable habitats. Other aspects of a species like behavior can also be affected by anthropogenic activities. There are however subtle extreme effects that can only be established with extensive studies. A good example is the impaired breeding as a result of stress as seen in birds (Watson, 2002). This can as well happen to other species especially when the breeding areas are directly altered by human activities consequently affecting the recruitment of a species. When there is no recruitment, the species practically sinks into extirpation/extinction. Such effects are sometimes obscure and can be hidden by the sighting of healthy adults in such places as in the background, a species loss is effectively overshadowed by blanket conservation. The present study presents the effects of anthropogenic threats to the herpetofaunal community in Cherangani Hills Forest.

But how essential are forests to herpetofauna so that forest disturbance becomes so important? Stating that forests serve as habitat is perhaps too general, making the effects of disturbance to appear superficial for several reasons. Firstly, the vegetation stabilizes environmental variables specifically temperature and humidity (Montagnini and Jordan, 2005; Lavelle and Spain, 2001) which are vital for the cold blooded herps (Julian, 2008; Zug *et al.,* 2011). This external constancy stabilizes the physiological processes in the herps allowing them to carry on with other activities instead of behaviorally regulating their body temperature. Secondly, the shed leaves by the forest vegetation provides leaf litter which is by itself a microhabitat for the litter specialists (Ernst and Rodel, 2005; Ernst *et al.*, 2006). Thirdly, the growth of roots in the soil together with the humus from decomposing plant parts reduce the compactness of soil particles (Lavelle and Spain, 2001) which then makes it possible for subterranean herps to move and carry out other activities within the soil (Measey and Barot, 2006). Fourthly, plant leaves provide breeding sites for some species (Channing and Howell, 2006; Malonza, 2012) ensuring recruitment and consequently the continuity of such species. Forest canopy also provides a home and hunting ground for arboreal species such as snakes which prey on birds and chicks found in the highly weaved nests (Wagner and Böhme, 2007).

The above links between herps and forests informed the selection of the threats under this study as each affects one or more microhabitat(s) directly or indirectly. These include logging, debarking, grazing, charcoal burning and the invasive plant, *Cestrum aurianticum*. These, together with the vulnerability to changes in their environment makes herpetofauna a good candidate taxa to study how biodiversity respond to disturbance especially in forest environments. Additionally, herps have limited/slow dispersal ability (Blaustein *et. al*., 1994) which hinders their ability to migrate from affected areas making it easier to study how they are affected. The distribution of herpetofauna has been found to be affected by human factors

(Parmesan and Yohe, 2003; Sasaki *et. al*., 2005) but the response appear to vary with species (Wagner *et al.*, 2008).

Every area should also be given individualized attention since other factors like elevation which have an antagonistic relationship with herpetodiversity, also influence the diversity of herpetofauna (Channing and Howell, 2006; Roelke and Smith, 2010; Malonza, 2015). High altitude areas are known to have lower herpetodiversity and the few species are still being lost (Morrison and Hero, 2003; Pounds *et al.*, 2006). This makes herpetofaunal surveys in such areas as Cherangani Hills Forest crucial for understanding the causes of such losses and subsequent development of protection models.

In this paper, we compare different habitat types within the forest complex in terms of herpetofaunal richness, diversity and threats in an effort to inform conservation on what to protect, where to protect and what to guard against. This aims to increase the success of conservation at the local level through identification of areas with higher and unique herpetodiversity.

Materials and methods

Study Area

Cherangani Hills are located in the North-Western part of Kenya in the Rift Valley bordering the Elgeyo escarpment to the east and Mount Elgon to the west. Administratively they lie within Elgeyo-Marakwet, West Pokot and Trans-Nzoia Counties. The forest covers an area of about 1200 km^2, 956.5 km^2 of which is gazetted into reserves comprising 13 administrative blocks. The closed-canopy forest forms 605 km^2, 40 km^2 is under cultivation and plantations, while the rest comprises of formations of bamboo, scrub, rock, grassland, moorland or heath. The forest blocks are Kapkanyar, Kapolet and Kiptaberr Forest Reserves which together form the large western forest block of 200 km^2. The eastern block is composed of Lelan, Embombut, Kerrer, Kaisungur, Toropket, Chemurkoi, Kipkunurr, Cheboyit, Sogotio and Kapchemutwa. The south-eastern block runs along the escarpment crest, where the forests are fragmented and separated by extensive natural grasslands, scrub and farmland (Birdlife international, 2009).

Cherangani Hills forest ecosystem is located in a hilly terrain, with deep valleys along river beds. It is an old fault-block formation of non-volcanic origin, with the hills forming an undulating upland plateau on the western edge of the Rift Valley. To the east is the Elgeyo Escarpment which drops rapidly to the floor of the Kerio Valley. In the west is a gentle fall which sinks into the plains of Trans-Nzoia County. The highest point lies at an altitude of 3365 m at Cheptoket Peak in the north-central section.

The climate is relatively wet and humid. Annual rainfall varies from 1200 mm in the east to at least 1500 mm in the wetter west, which catches the moist prevailing winds from Lake Victoria, (Birdlife International, 2009). The long-rain season for the rains is mainly in April, May and June and sometimes might extend to August. The short-rains season is in October/November, and December to March is usually the dry season. Temperatures range from 25-30 ^{0}C though there has been a change of seasonal weather regime possibly due to the depletion of the forest (Birdlife International, 2009).

The Cherangani forests are important for water catchment, and sit astride the watershed between the Lake Victoria and Lake Turkana basins (Akotsi and Gachanga, 2003; Birdlife International, 2009). The streams to the west of the watershed feed the Nzoia river system, which flows into Lake Victoria while those to the east flow into the Turkwel and Kerio river systems which empty into Lake Turkana.

Species sampling

Sampling was done from January to June 2015, a period that covered both wet and dry seasons. Two herpetofaunal sampling methods were used. The first method was the time-limited-search (Karns, 1986; Heyer *et al.,* 1994) and Sutherland (1996). Time for sampling was dependent on the species behavior, i.e. when the animals were active, and the prevailing weather conditions. Reptile sampling was mainly done in the morning and late afternoon while night sampling was done for amphibians (mainly frogs) and other nocturnal species. In addition to species sighting, acoustic survey, which is more effective for collecting data on amphibians (Malonza, 2010; Dostine *et al.,* 2013), was used. The voice detection allowed for species distinction as well as individual counts. An average of ten repetitions were noted, a reduction from twenty used by Jørgensen (2000) to ascertain that it is the same individual in order to avoid multiple recording of the same individual. Effort was also made to get to the source of the call to capture and/or photograph the species to assist in identification. The method was nested within the time-limited-searches

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The second method was trapping using pitfall traps associated with drift fence. This method targeted the crawling species like frogs and lizards in the forests (Ryan *et al.,* 2002; Doan, 2003; Rodel and Ernst, 2004; Willson and Gibbons, 2009; Sung *et al.,* 2011). Five 10 liter buckets were buried in flush with the ground arranged in an X formation to ensure trapping from all directions. Water that might have drowned the trapped animals drained through holes bored at the bottom of the buckets and an escape string was tied at the edge of the bucket to allow for small mammals like mice and rats to escape (Karraker, 2001, Sung *et al.,* 2011).
Opportunistic records were also made when species were encountered outside the sampling times to enrich the data and increase the species detection. Collected specimens were euthanized using MS222 for amphibians and pentobabitone for reptiles. Muscle tissues were then obtained and preserved in absolute alcohol for DNA analysis before the specimens were preserved in 10% formalin. Field identification was done where possible from the photographs and collected specimen and where this was not possible, they were taken to the museum for identification. This was done with reference to the published taxonomic keys by Spawls *et al.,* 2002 for reptiles and Channing and Howell (2006) for the amphibians. The amphibian taxonomy followed Frost *et al.,* (2006) and Frost (2010).

Species distribution in the different habitats was determined from a table which put the species against the habitats, where each presence was marked with 1 and absence was marked with 0. This was important in the determination of habitat specialist and generalist species.

Threats sampling

The threats observed were; invasive plant species (*Cestrum aurianticum*), deforestation, bark ringing, charcoal burning, paths/tracks and grazing. Each threat was identified based on the available indicators for each. The presence of the invasive plant was noted through observation of the plant in the sampling site whereas presence of kilns and charcoal chars indicated charcoal burning activities. Tree stumps and logs indicated logging activities while presence of ringed trees, dead or alive indicated debarking. Grazing was identified from the presence of the livestock, their hooves or dung while paths and tracks were recorded where they were evident. The threats were recorded as either present denoted as 1 or absent and denoted 0 for each habitat. As such, the threat values were 0≤6 representing the high and low threat levels.

Data analysis

The TLS data from each habitat was analyzed in ESTIMATE S 8.2 (Colwell, 2009) to determine the Shannon-Weiner diversity index for the different habitat types with the accumulation curves generated at 1000 randomizations. These were then compared using One-Way ANOVA to test for any significant differences in STASTICA8. The distribution of the species in different habitats was determined from the table of species and habitats by totaling the values from each habitat with the species. This was then expressed as a percentage of the total.

The total threat values were determined by summation of the threat values observed in each site. The relationship between the threats and species diversity and richness was determined from a scatter graph of threats against diversity in Excel.

Results

Species diversity and richness

A total of 33 species were observed throughout the study. The highest number was recorded from the scrubland (S=15), followed by the wetlands (S=12), forests (S=9) and farmlands (S=6). The lowest number was recorded from the rocks and glades which had 4 and 3 species, respectively (Table 1)

Table 1. Herpetofauna richness and diversity in different habitat types in Cherangani Hills.

Habitat type	No. of species (S)	Diversity (H')
Glades	3	0.76
Rocks	4	0.79
Forests	9	1.70
Wetlands	12	1.19
Farmlands	6	1.12
Scrubland	15	1.88

The scrubland had the highest diversity (H'=1.88), followed by the forest (H'=1.70) then the wetland (H'= 1.19). Farmlands, rocks and glades had diversity of H'= 1.12, 0.79 and 0.76, respectively (Table 1). The differences between the means were significant between all the habitat types except between farmland and wetlands (t= 0.7048, p>0.05) and between rocks and glades (t= 0.6605, p>0.05, Table 2)

Table 2. ANOVA comparison of the diversity in the different habitat types in Cherangani Hills. The diversity means were significantly different between all the habitat types except between farmland-wetland, and rocks-glades.

Habitat type	Farmland	Wetland	Rocks	Glade	Forest
Farmland	0	0.7048	0.01864	0.000284	0.000116
Wetland	1.808	0	0.000339	0.000116	0.000137
Rocks	4.437	6.245	0	0.6605	0.000116
Glade	6.346	8.155	1.91	0	0.000116
Forest	8.855	7.047	13.29	15.2	0

In terms of habitat distribution, 81.8% of the species were observed in only one habitat type, 9.1% were detected in two habitats, and 6.1% were found in three while only 3% were spotted in more than three habitats (Table 3, Annex 1).

Table 3. Distribution of herpetofaunal species in Cherangani Hills Forest habitats. Majority of the species exploited only one type of habitat and only one was found in more than three habitats.

Number of habitat occupied by species	**Inhabiting Species**	**Percentage %**
1	27	81.8
2	3	9.1
3	2	6.1
5	1	3

An important field observation was that only one glade out of the five sampled had herpetofauna and the puddle frog *Phrynobatrachus graueri* was restricted to two wetlands with distinct polymorphs.

There were at least three types of threats in every habitat type. No relationship was found between the agents of disturbance and herpetofaunal richness (R^2=0.186) but there was a positive relationship between threats and herp diversity (R^2=0.5808). The distribution of agents of disturbance varied in the habitat types (Table 4).

Table 4; Distribution of herpetofaunal richness and diversity and the agents of disturbance in the different habitat types of Cherangani Hills Forest. Note the ubiquity of grazing and paths in the habitats and the presence of all the threats in the forest.

	Grazing	Logging	Debarking	Invasive *Cestrum*	Paths/Tracks	Charcoal Burning	Diversity (H')	Richness (S)
Forest	1	1	1	1	1	1	1.7	9
Wetland	1	0	0	0	1	0	1.19	12
Glade	1	1	0	0	1	0	0.76	3
Rocks	1	0	0	0	1	0	0.79	4
Farmland	1	1	0	1	1	1	1.12	6

Discussion

The results show just how specialized herpetofaunal species in Cherangani Forest are in terms of their habitat preference.

The high number of species richness and diversity recorded from the scrubland can be attributed to the low altitude relative to the other habitat types. Herpetodiversity have been found to reduce with increase in altitude (Channing and Howell, 2006; Roelke and Smith, 2010). The wetlands had more species than the forest and the other high elevation habitats such as forests, rocks and glades. This could be attributed to the fact that aquatic habitats are more stable as far as water supply and associated characteristics are concerned (Abell, 2002). The stability in these wetlands is further increased by the fact that they were found within the forests, which reduced water evaporation by reducing the wind blowing over the wetlands and also the radiation heating the water (Montagnini and Jordan, 2005; Carson and Schnitzer, 2008). Since water is crucial for the herp species, especially the amphibians which need water for breeding and maintenance of the narrow physiological range (Julian, 2008), it was expected that their presence would be more in the wetlands than in the other habitats with limited water supply. In addition, in amphibians even the species that do not spend their lives entirely in wetlands like toads, do congregate in the wetlands during the wet season to breed (Channing and Howell, 2006). The species composition in the wetlands consisted predominantly of amphibians which were also the dominant herp group. In fact only two species of reptiles (*Philothamnus battersbyi* (Loveridge, 1951) and juvenile *Trioceros nyirit* (Stipala *et al.*, 2011) were recorded from the wetlands, which is normal owing to the fact that reptiles are not as dependent on water as amphibians. Their occurrence in the wetlands could have been to feed on the amphibians and insects attracted by the wetlands. Forests were next in species richness. It has been found that the closed canopy in the forest covers the ground lying below, and thus reduces the effects of wind and solar radiation and their effects on the humidity and temperature below the trees (Crawford and Semlitsch, 2008). This stability is crucial for the herps whose activities are controlled by the variations in the environmental conditions predominantly temperature and humidity (Alibardi, 2003; Zug et al., 2011). The study revealed some unique forest associated species such as a tree frog, *Hyperolius acuticeps* (Ahl, 1931) and a forest snake *Thrasops jacksoni* (Günther, 1895).

Forests are also responsible for leaf litter, which provides a microhabitat for some of these forest species (Nguku, 2009; Whitefield *et. al*., 2014). The switch between the wetland and forest diversity and richness can be attributed to the dominance of a few species in the wetland notably *Amietia angolensis* (Bocage, 1866) and *Phrynobatrachus graueri* (Nieden, 1911) which caused an imbalance in the evenness. The dominance of a few species in a habitat is known to lower its diversity (Gotelli and Chao, 2013)

The low diversity and richness observed in the farmlands can be attributed to the high intensity of human activities and the heavy human presence in this habitat type. Consequently, only the species that could withstand heavy human presence could be found in these areas (Orserand Shure, 1972; Miller, 2013). The common species observed in the farmland were the generalist lizard species, *Trachylepis striata* (Peters, 1844) and the endemic chameleon *Trioceros nyirit* which utilized the farms and the forest edges which are exposed to radiation (Stipala *et. al.* 2011). This enabled the chameleons to easily bask in the morning as they tried to control their body temperature.

The lowest diversity and richness was recorded in the glades and rocks. This observation could be ascribed to the open nature of the habitats which predisposed the species to constant fluctuations of environmental conditions. Because of this, the species in the rocks respond appropriately to the changes such as intolerable high temperatures by taking cover under the crevices and basking on the rocks when they needed heat. The *Adolfus jacksoni* (Boulenger, 1899) and *Tachylepis striata* were observed basking or carrying out their normal activities such as hunting, fighting and feeding closer to rock crevices, where they could also quickly dash into whenever they felt threatened. Similarly, species in the glades could hide in aardvark burrows and bask on grass tufts present within their habitats. This was observed in *Trachylepis varia* (Peters, 1867) and *T. irregularis* (Lönnberg, 1922) in the glade where most of the individuals sampled were next to a burrow. They easily retreated into these burrows whenever they felt threatened by the presence of humans, predators or grazing animals.

The difference in species composition between the rocks and glades could be attributed to species habitat preference given that the two dominant herps in the glades (*Trachylepis varia* and *Trachylepis irregularis*) prefer glades though *T. varia* can also inhabit rocky grounds and forests edges (Spawls *et. al.*, 2002; Malonza, 2011). In the rocks, there was *Trachylepis striata*, which is a generalist species, and *Adolfus jacksoni* which is a forest associated species. Although *A. jacksoni* is a forest species, it prefers open patches within the forest as reported by Spawls *et. al.,* (2002) and observed by Wagner and Böhme (2007) in Kakamega forest. Roelke and Smith (2010) also had similar observations in Rwanda. These species thus had varied habitat preferences.

Threat distribution

The nature and intensity of the human induced threats to a natural system is a reflection of the socio-economic organization of the community. In Cherangani area, livestock is at the core of the social and economic activity (Birdlife International, 2014). This is responsible for the heavy presence of the livestock in the forest ecosystem as they graze in all habitat types and drink in the wetlands. On the other hand, grazing is a form of intrusion that negatively affects the wild animals. Beirne *et al.* (2009) found this activity to reduce species richness while Hadden and Westbrooke (2012) found a significant relationship between herpetofaunal species richness and the level of past grazing pressure and ground vegetation structure. For the herps, the stumbling livestock destroy their ground micro-habitat and may step on the animals directly, especially those living in litter. It also opens up the habitat at the ground level, predisposing the habitat to changes in the microclimate conditions like humidity and temperature changes. Mabberley (1975) and Birdlife International (2003) both put logging and grazing among the major threats to wildlife in Cherangani Hills.

Similar disturbance is brought about by the presence of paths and tracks, indicating human presence in these habitats. The effect of these to herpetofauna is the introduction of stress due to the presence of the livestock and herders within their habitats. Given that different species have varying degrees of tolerance to human presence (Spawls *et. al.,* 2002; Wagner and Böhme, 2007), those that cannot cope with such disturbance are forced to hide till the livestock and/or people have moved on. In areas where they cannot find opportunities of concealment, they are forced to migrate. This may account for the absence of any species in the other glades which did not have cover such as the aardvark burrows used by *Trachylepis irregularis* and *T. varia* in Kiptaber glade.

Logging, charcoal burning and debarking are all extractive activities that reduce the forest cover. Other studies have found a relationship between forest cover, road density and the wetland community composition (Houlahan and Findlay, 2003). Extensive logging may also lead to habitat conversion, fragmentation and the subsequent reduction, change or complete loss of herpetofauna community (Curtis and Taylor, 2003). Habitat fragmentation in itself has far reaching effects on the population such as limited dispersal, restricted gene pools and the consequential fitness (Measey *et al.*, 2003; Andersen *et al.*, 2004). The consequence of habitat conversion is exemplified in the present study where the open habitats like rocks and glades had the lowest richness and diversity compared to the other habitats.

The present study signposts the significance of the forests not just as vegetation, but as habitat to other forms of biodiversity. It also shows that some of the human activities targeting the vegetation may have far reaching effects on the other living things in such forests. Given that the other habitats are found within the forests, the forests may be serving as a buffer, cushioning the other forms of biodiversity from immediate effects of human disturbance. This may be demonstrated by the absence of species in most of the glades, which may be natural or may have resulted from extreme cases of logging. The sprawling nature of the forest may be advantageous to the few species in this high altitude environment as it provides ample refuge, consequently cushioning the species from the effects of disturbance. Watson (2003) found an antagonistic relationship between the size of a habitat and the response of avian species to disturbance. This might explain the relationship between the threats and herpetofaunal diversity in this study given the expansive size of Cherangani Forest.

Conclusion and recommendations

This study showed most of the species to be distributed in specific habitat types within the forest with only a few being in more than one habitat. This should inform protection of these habitats because of how unique each habitat is in terms of herp exploitation. There is also need to protect the forest because of the important influence the vegetation has on these habitats making them habitable by herpetofauna. Though the study did not establish a relationship between the threats and herpetodiversity, an observation attributable to the expansive nature of the forest, effort to reduce such threats should be increased as the threshold for realizing these effects has not been established. More so because the open habitats had very low richness and diversity compared to those in closed environments.

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Annex 1. Distribution of herpetofaunal species in different habitat types of Cherangani Hills Forest. Majority of the species were limited to one habitat type and only one was found in more than three habitat.

Species	**Farmland**	**Forest**	**Glade**	**Rock--outcrop**	**Rocks**	**Wetland**	**Total**
Acanthocercus atricollis	0	0	0	1	0	0	1
Adolfus jacksoni	0	1	0	0	1	0	2
Agama lionotus	0	0	0	1	0	0	1
Amietia angolensis	0	1	0	0	0	1	2
Amietophrynus kisoloensis	1	1	0	0	0	1	3
Boaedon fuliginosus	0	0	0	0	0	1	1
Broadleysaurus major	0	0	0	1	0	0	1
Dispholidus typus	0	0	0	1	0	0	1
Duberria lutrix	1	0	0	0	0	0	1
Gerrhosaurus flavigularis	0	0	0	1	0	0	1
Hemidactilus angulatus	1	0	0	0	0	0	1
Hyperolius acuticeps	0	1	0	0	0	0	1
Hyperolius cinamommeoventris	0	0	0	0	0	1	1
Latastia longicaudata	0	0	0	1	0	0	1
Naja melanoleuca	0	1	0	0	0	0	1
Philothamnus battersbyi	0	0	0	0	0	1	1
Phrynobatrachus graueri	0	0	0	0	0	1	1
Psamorphis sudanensis	0	0	0	1	0	0	1
Ptychadena	0	0	0	0	0	1	1

Species	Farmland	Forest	Glade	Rock--outcrop	Rocks	Wetland	Total
anchietae							
Ptychadena mascarinensis	0	0	0	0	0	1	1
Telescopus dhara	1	0	0	0	0	0	1
Thrasops jacksoni	1	1	0	0	0	0	2
Trachylepis bayonii	1	0	0	0	0	0	1
Trachylepis irregularis	0	0	1	0	0	0	1
Trachylepis quinquetaeniata	0	0	0	1	0	0	1
Trachylepis striata	1	1	1	1	1	0	5
Trachylepis varia	0	0	1	0	0	0	1
Trioceros ellioti	1	0	0	0	0	0	1
Trioceros hoehnelii	0	0	0	0	0	1	1
Trioceros nyirit	1	1	0	0	0	1	3
Varanus albigularis	0	0	0	0	0	1	1
Varanus niloticus	0	0	0	0	0	1	1
Xenopus victorianus	0	0	0	0	0	1	1

Distribution of Avifauna Diversity in Vegetation Zones of Mt. Elgon Forest Ecosystem

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Abstract

Kenya's montane forests have received little attention regarding studies on the diversity and distribution of bird species. This makes it hard to understand how forest management decisions impact on the bird populations in these forests. We studied the diversity, distribution and abundance of avifauna species in different vegetation zones of Mount Elgon Forest Ecosystem. Assessment was carried out in four habitats within the forest ecosystem, namely: open montane forest, dense montane forest, bamboo zone, sub-alpine montane heath and cultivation areas. The study employed the common bird monitoring approach, which entailed use of line transects and point counts in each habitat. Birds were identified using the Dale Zimmerman's bird guidebook and radio call-back using preinstalled voice recognition software. A total of 211 bird species were recorded, six of which were species of conservation concern. Of the recorded bird species, 96 were forest habitat specialists, 87 were forest generalists, while 28 were forest visitors. The dense mixed montane forest within the national park had the highest number of species of birds at 66, while the bamboo zone within forest reserve had the least number of species at 41. The dense montane forest had 51 bird species, the sub-alpine and the disturbed mixed montane forest had 49 each, while the mixed montane forest areas under PELIS had 45 species. The results suggest that the national park had relatively more bird species than the forest reserve, most of which were habitat specialists. This was mostly caused by lack of external interference to bird habitats inside the national park. Up to 31 bird species that we expected to record during this study were missing. We suspect that most of these may have emigrated from the forest ecosystem due to forest degradation. Findings of the study suggest that forest degradation is causing loss of bird species in this forest ecosystem.

Key words: Forest degradation, Bird species distribution, Sustainable natural resource management

Introduction

The afromontane forest cover has been decreasing in Kenya over the past three decades due to forest degradation and deforestation. The situation has affected the populations of animal species that depend on these forests for food and as habitat. Some of the most affected animal species are birds whose population greatly depends on the availability of adequate tree cover (BirdLife International, 2000; Gregory *et al.*,2003). Many of the bird species are habitat specialists because of their feeding, breeding or survival strategies (Skorka *et al*., 2006). The continued reduction in closed canopy forest cover in the afromontane zone has made them the focus of attention. The situation is exacerbated by the fact that forest degradation is likely to render the birds of this ecosystem highly vulnerable to climate change, which may lead to loss of biodiversity (Zuckerberg, 2017). Consequently, forest management strategies should take into consideration their likely effect on the distribution and abundance of bird species, particularly forest habitat specialists.

Despite the emerging need for sustainable management of the afromontane forest ecosystem, for the good of bird species, little is known about the species, distribution and abundance of these birds in the different vegetation zones of the afromontane ecosystem. This is likely to hamper efforts to conserve them within the larger forest management plan. Being an important indicator of forest ecosystem integrity, the conservation of birds is an important component of any sustainable forest management strategy. The situation is more serious in Mount Elgon Forest Ecosystem where a great deal of the forest vegetation has been fragmented, and is suspected to have adversely affected bird populations. Of more concern are forest habitat specialists, which may have been significantly affected in the process.

In this paper, we present the distribution and abundance of different bird species in the various vegetation zones of Mount Elgon Forest Ecosystem, an afromontane forest ecosystem located in western Kenya. The paper lists the birds by their distribution pattern and relative abundance in the various vegetation zones. It identifies also bird species of conservation concern. Findings of the study are expected to inform the development of an integrated forest management plan with regard to conservation priorities of different vegetation zones.

Materials and Methods

Study area

The study was carried out in Mount Elgon Forest Ecosystem, one of Kenya’s five major water towers and the second highest afromontane forest ecosystem in the country. The forest ecosystem is a biodiversity hotspot of global significance, supporting several endemic plant and animal species. It is located 01^{o} 07′ 06″ N and 34^{o} 31′ 30″ E about 100 km north-east of Lake Victoria (Mwaura, 2011). The forest ecosystem is the source of Rivers Nzoia, Turkwel and Malakisi. Despite its height, the average slope angle of the mountain is less than 4 degrees giving it very gentle slope. The climate of Mount Elgon is cool and moist to moderate dry. It has a bimodal rainfall pattern with an annual rainfall of 1,500 – 2,000 mm (MUIENR and NMK, 2005). The rains come in March to May and September to November. The dry seasons run from June to August and from December to March. The mean temperature of the ecosystem ranges between 14^{o}C in the high altitude moorland zone and 24^{o}C in the mixed montane forest at the slopes of the mountain. The forest ecosystem supports various vegetation types and rare species from the slopes to the peak of the mountain. It also supports aforest adjacent population of about 2 million people, a majority of whose livelihoods and economic activities depend solely on the goods and services that they derive from the forest ecosystem.

Birds' survey method

We assessed the bird species distribution and abundance using the common bird monitoring (CBM) approach that combines a number of sampling methods and is flexible within and between habitat types (Zimmerman *et al*., 1999). The forest was stratified into habitats based on vegetation zone, namely: open montane forest, dense montane forest, bamboo zone, sub-alpine montane heath and cultivation areas (sites under plantation establishment livelihood and improvement programme - PELIS). In each habitat, 1 km line transects were laid in the orientation of the vegetation zone. Birds were recorded on either side of the transect by species and number of individuals of a species. Efforts were made not to disturb the birds in order to ensure that they did not fly away and in the process end up being counted more than once. Transects were located at least 500 m apart. Birds were identified by behavior, size, sex, nests and sound using the Dale-Zimmerman's bird guide book (Zimmerman *et al*., 1999). In a few cases where it was hard to identify a particular species of bird, a pre-installed radio call-back software, which was installed in a smart phone, was played to serve as a bird of the same species. Birds would respond to calls from those of the same species. The radio call-back software also enabled us to identify birds that we did not know. We matched the sounds that they made to those in the radio call-back software.

Birds species richness was derived by counting the number of species of birds in a vegetation zone. Relative abundance was calculated as the number of members a given bird species expressed as a proportion of the total population of all species of birds in a vegetation zone.Species of conservation concern comprised those found in the IUCN's red list category or those having a restricted altitudinal range.

Results and Discussion

Distribution of bird species in vegetation zones

A total of 211 bird species was recorded in the Mt. Elgon Forest Ecosystem, of which 96 were forest habitat specialists (FF), 87 were forest generalists (F), while 28 were forest visitors (f).The dense mixed montane forest within the national park was the vegetation zone with the highest number of species of birds at 66, while the bamboo zone within forest reserve had the least number of species at 41 (Figure 1).

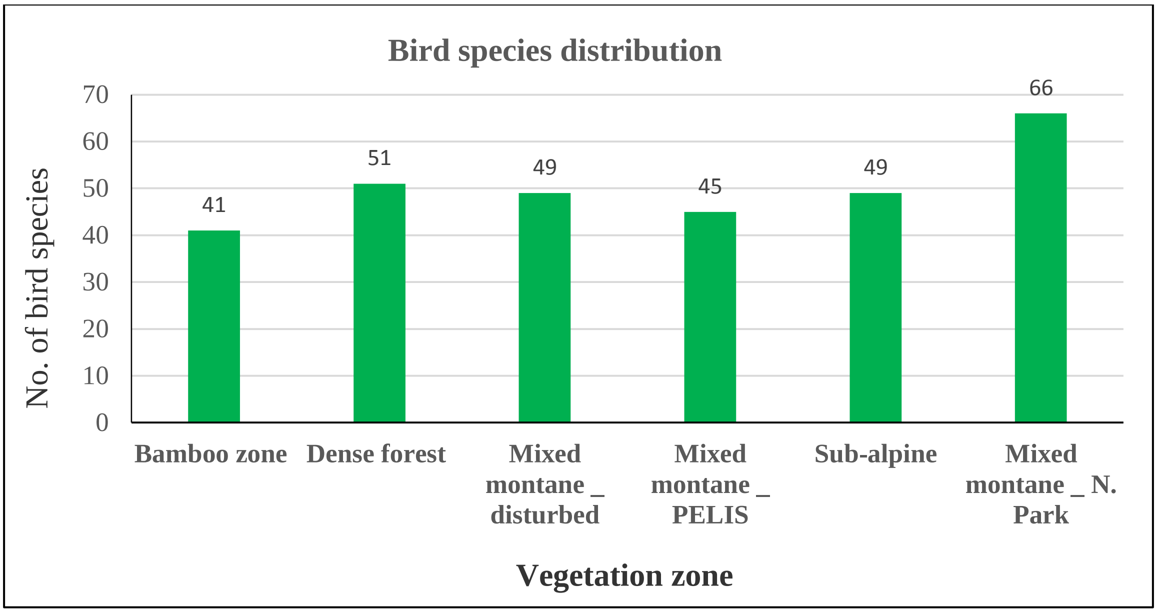

Figure 1. Distribution of bird species in different vegetation zones of Mt Elgon Forest Ecosystems

The results suggest that relatively less disturbed habitats harboured more bird species than commonly disturbed ones. For instance, the national park was not exposed to external disturbance and hence had more species of birds than other vegetation zones. The high number of bird species in the dense montane forest and the sub-alpine montane heath was not surprising given the low level of vegetation loss in these two habitats. The bamboo zone in the forest reserve was, however, largely disturbed by elephants and livestock, which commonly grazed and browsed in it, destroying bird nests in the process. The mixed montane forest areas that were subjected to cultivation through PELIS had more bird species than previously expected. This was likely caused by the fact that grain-eating birds found it suitable as a habitat. The granivores comprised mainly forest generalists and forest visitors.

Relative abundance of bird populations in vegetation zones

The sub-alpine montane heath had the higher population of birds, representing 28.9% of all the birds within afromontane forest ecosystem. It was closely followed by the bamboo zone (Table 1). These results suggest that the bird species of the bamboo zone were relatively fewer, but they consisted of habitat specialists whose individuals were restricted to the zone. The same applies to the sub-alpine zone. The other vegetation zones may have had higher or fewer bird species, but majority of them were habitat generalists whose individuals were scattered in other habitats, hence recording lower relative abundance.

Table 1. Relative abundance of bird population in different vegetation zones of Mt Elgon Forest Ecosystem

Vegetation zone	Bird species distribution	Relative abundance (%)
Bamboo zone	41	27.6
Dense montane forest	51	13.7
Mixed montane _ disturbed	49	6.9
Mixed montane _ PELIS	45	12.2
Mixed montane_ N. Park	66	10.7
Sub-alpine	49	28.9

The most abundant bird species in the disturbed mixed montane forest in forest reserve were the Common Bulbul, Common Scimitarbill and Hadada Ibis (Table 2). In the areas under PELIS in the mixed montane forest the most abundant species of birds included Singing Cisticola, Grey-headed Sparrow and Bronze Mannikin. The bamboo zone had Singing Cisticola, Black-headed Waxbill and Black Saw-wing Swallow as the most dominant bird species. The Common Bulbul, Chubb's Cisticola and Bronze Mannikin were the most abundant bird species in the dense montane forest. The sub-alpine heath had the Wire-tailed Swallow, Red-rumped Swallow and White-rumped Swift as the most dominat species of birds. The African Citril, Common Bulbul and Yellow-crowned Canary were the most dominant species in the mixed montane forest within the national park.

Table 2. Relative abundance of the most abundant bird species in vegetation zones of Mt Elgon Forest Ecosystem

Vegetation zone	Most abundant bird species	Relative abundance (%)
Mixed montane _ disturbed	Common Bulbul	15.0
	Common Scimitarbill	13.0
	Hadada Ibis	5.3
	Singing Cisticola	15.0
Mixed montane _ PELIS	Grey-headed Sparrow	11.7
	Bronze Mannikin	10.9
	Singing Cisticola	16.2
	Black-headed Waxbill	13.2
Bamboo zone	Black Saw-wing Swallow	12.2
	Common Bulbul	18.8
	Chubb's Cisticola	17.3
Dense montane forest	Bronze Mannikin	15.9
	Wire-tailed Swallow	14.4
	Red-rumped Swallow	13.7
Sub-alpine	White-rumped Swift	12.3

Vegetation zone	Most abundant bird species	Relative abundance (%)
	African Citril	12.8
	Common Bulbul	11.9
Mixed montane _ N. Park	Yellow-crowned Canary	8.5

Species of conservation concern

Six of the 211 bird species comprised those listed to be of conservation concern, either by appearing in the IUCN's red list category or by having a restricted range (Table 3). These include Sharpe's Longclaw, African Crowned Eagle, African Golden Oriole, Lammergeier (Bearded Vulture), Splendid Glossy Starling and White-breasted Cuckoo-shrike. For instance, the Sharpe's Longclaw is listed as globally threatened due to rapid loss of range in the tussock grasses as a result encroachment of other land use e.g. heavy grazing into the subalpine montane heath. It depends of the tussock grasses for nesting (at the base of tussock grasses), feeding (on insects such as grasshoppers and beetles found at the base of tussocks) and camouflage from predators. It is therefore classified as endangered. Apart from the Sharpe's Longclaw, which was found in the sub-alpine zone, the other five species were located within the national park, which illustrates that forest degradation has significantly affected their population in the forest reserve leaving only a few in the national park. Even within the national park, their relative abundance was just 0.2% of the total bird population. Ecosystem management strategies must strive to conserve the habitats of these bird species.

Table 3. Seven bird species of conservation importance in Mt Elgon Forest Ecosystem

Vegetation zone	Bird species	Total count	Relative abundance (%)
Sub-alpine	Sharpe's Longclaw	**2**	0.16
Mixed montane - N. Park	African crowned eagle	**1**	0.21
Mixed montane - N. Park	African Golden Oriole	**1**	0.21
Mixed montane - N. Park	Lammergeier (Bearded Vulture)	**1**	0.21
Mixed montane - N. Park	Splendid Glossy Starling	**1**	0.21
Mixed montane - N. Park	White-breasted Cuckoo-shrike	**1**	0.21

Missing species of birds

Based on the altitudinal range of this afromontane forest and studies in similar water towers, we had expected to record at least an extra 31 species of birds (Appendix 1) but we missed them. This could be because our survey did not involve night walks since some of the birds are nocturnal. It is also possible that forest degradation may have made the birds to migrate to other forest ecosystems.

Conclusion

The distribution of bird species in Mt Elgon Forest Ecosystem is affected by the level of forest degradation. Relatively more intact habitats have more species of birds than in degraded zones. Zones within the national park have more bird species than zones with the forest reserve. Within the forest reserve, the sub-alpine zone has the highest species of birds. The relative abundance of birds within vegetation zones does not necessarily follow the species distribution pattern because populations of some habitat specialists are still restricted to degraded habitats. Six species of conservation concern are located in this forest ecosystem. One is found within the sub-alpine heath, while the rest are within the national park. Findings of the study suggest that forest degradation is causing loss of bird species in this forest ecosystem. Thus, ecosystem management strategies should address the conservation of various bird habitats of this forest ecosystem.

Appendix. List of bird species that we expected to find in Mt Elgon Forest Ecosystem, but were missing

S/no.	Bird species
1.	Banded Prinia
2.	BoranCisticola
3.	Olive-green Camaroptera
4.	EquitorialAkalat
5.	Grey-chested Illadopsis
6.	Cameroon SombreGreenbul
7.	AnsorgesGreenbul
8.	Shelley's Greenbul
9.	Toro-olive Greenbul
10.	1Honey-guide Greenbul
11.	Blue-shouldered Robin-chat
12.	White-breasted Negrofinch
13.	Eastern Double-collared Sunbird
14.	Green Sunbird
15.	Violet-backed Starling
16.	Stuhlmann's Starling
17.	Square-tailed Drongo
18.	Velvet-mantled Drongo
19.	Eastern Nicator

S/no.	Bird species
20.	Red-shouldered Cuckoo-shrike
21.	Pink-footed Puffback
22.	Sooty Boubou
23.	Mackinon's Shrike
24.	Dusky-crested Flycatcher
25.	Dusky Tit
26.	Green Hylia
27.	Whistling Cisticola
28.	Brown-eared Woodpecker
29.	Buff-spotted Woodpecker
30.	Forest Wood-Hoopoe
31.	Blue-headed Bee-eater

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Participatory Forestry for Rehabilitation of Degraded Peri-Urban Mangroves in Kenya

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Abstract

Peri-urban mangroves in the West Indian Ocean region are threatened by over-harvesting of wood resources, habitat conversion, and pollution. Loss and degradation of these forests have negative effects on fisheries, shoreline stability, and resource sustainability. Initiatives to rehabilitate denuded mudflats were started in peri-urban mangroves of Mombasa County in Kenya. These included mapping of degraded mangrove areas, mass collection of mangrove propagules, establishment and maintenance of nurseries, out-planting, and monitoring of replanted mangrove areas. At least 30 members of participating communities were trained on principles of ecological mangrove restoration. A total of 190,610 mangrove seedlings raised in the nurseries were out-planted between 2007 and 2017. The following parameters were monitored in established plantations: survival/mortality of seedlings, growth performance in terms of height of seedling (m), stem diameter (cm). Stem internode counts and leaf area index (LAI) were not measured due to difficulties in identifying nodes in some dwarf trees and evidence of pruning in the plantations, respectively. Leaf area estimations were instead used to measure productivity by linking photosynthetic surface area to biomass accumulation. This paper presents preliminary results of these rehabilitation initiatives reforested mangrove areas. The results have wide applications in the region whereby mangroves have suffered abuse, removal and degradation.

Keywords: Participatory forestry, mangroves, Kenya

Introduction

Mangroves are complex tropical ecosystems that provide multiple goods and services to human society throughout the world (FAO, 1994). Ecologically, mangroves are known to provide habitat for fish and other wildlife (Saenger, 2002). It is estimated that 70 % of commercial coastal fisheries depend in one way or another on mangrove ecosystem (Barbier *et al.*, 2011). Mangroves are also known to play key role in coastal protection, pollution and water quality control, enhancement of sediment deposition, nutrient cycling, among others (McAlpine and Wotton, 2009). In the context of climate change, mangroves have been shown to be among the most carbon-rich forests in the world, containing an average of 1,023 Mg carbon per hectare; which is 3-5 times higher than any productive terrestrial forest (Donato *et al.*, 2011).This carbon is prone to be released back to the atmosphere when mangroves are degraded (Pendleton *et al.*, 2012). Locally, mangroves provide wood products in the form of poles, timber and as a material for building boats and houses, firewood, and charcoal.

Despite immense values provided by mangroves, they continue to be lost and degraded at alarming rate throughout the world (Spalding *et al.*, 2012). In Kenya, for instance, an annual loss averaging 0.7 % by area was reported between 1985 and 2010 (Kirui *et al.*, 2012). In peri-urban mangroves such as in Mombasa County, this loss has exceeded 80 % cover (Bosire *et al.*, 2003). While natural processes, such as sedimentation, may have contributed to habitat degradation, the major causes of losses of mangroves in Kenya has been associated with over-harvesting of mangrove wood products, conversion pressure, and pollution (Abuodha and Kairo, 2001). These forms of degradation have led to shortages of harvestable wood products, reduction in fishery, and increased shoreline erosion. There have been community efforts to restore degraded mangroves in Mombasa since 2007. A total of 190,610 saplings of *Rhizophora mucronata*, *Ceriops tagal*, *Bruguiera gymnorrhiza* and *Avicennia marina* were planted in degraded sites as mono-specific formations in Tudor and Mwache creeks of Mombasa. Nonetheless, subsequent growth and development monitoring has not been conducted to establish successes thresholds and drawbacks in mangrove ecological restoration of Mombasa County. Therefore, this study assessed vegetative development of the plantations by observing growth parameters of replanted species in different sites.

Materials and Methods

Study Site

Peri-urban mangroves of Mombasa County cover 3,771 ha fringing Tudor and Portreitz Creek (GoK, 2015). Dominant mangrove species are *Ceriops* tagal and *Rhizophora mucronata* growing as mono-specific stands and mixed stands together with *Avicennia marina*, *Sonneratia alba* and *Bruguiera gymnorhiza.* Approximately 1,850 ha of the forest is considered degraded (Mohamed *et al*., 2009; Bosire *et al.*, 2014). The study focused on Mwache Creek a constituent of Portreitz Creek and Mikindani of Tudor creek (Figure 1).

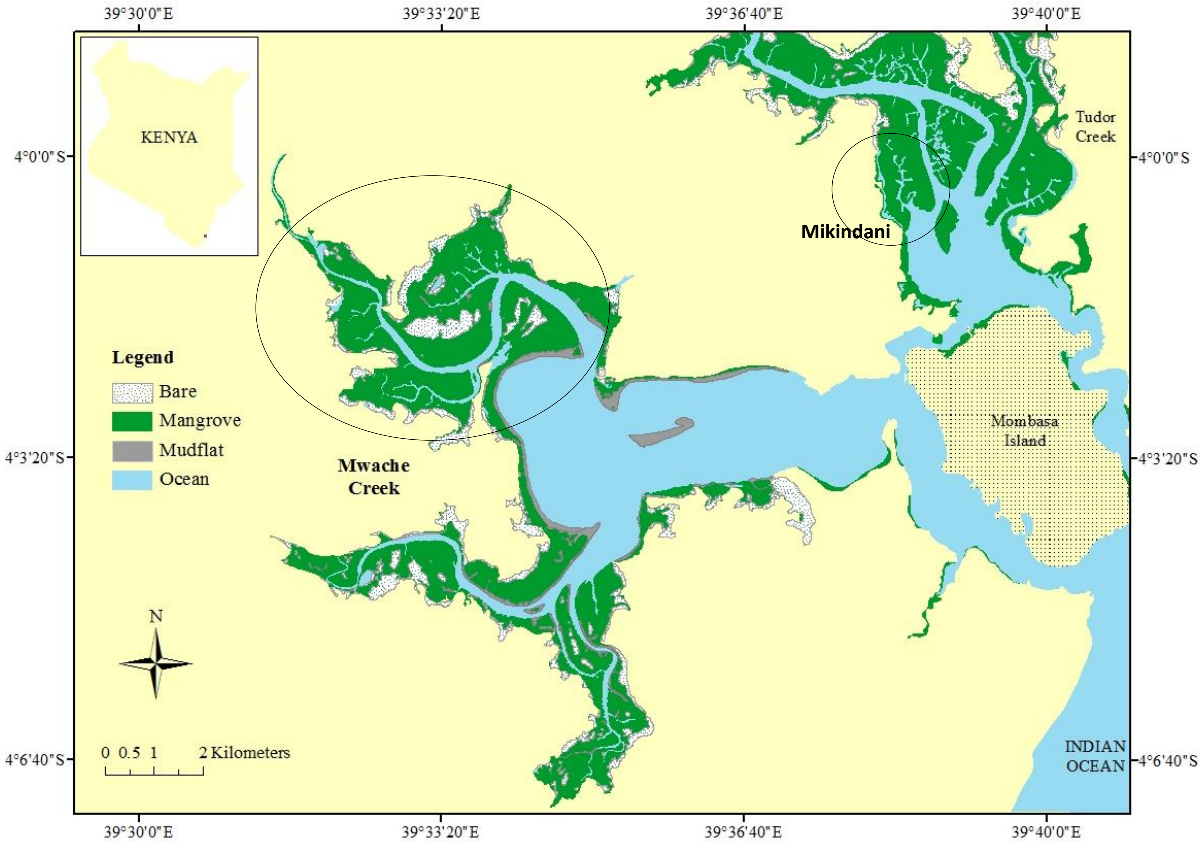

Figure 1. Peri-urban mangroves of Mombasa County

Study design

Observations focused on growth parameters consistent across all species, to facilitate comparison and replication of the monitoring practices. Stem diameter and height parameters were convenient across the investigated sites. However, some stands were subjected to secondary forestry management practices that would have compromised integrity and accuracy of derived Leaf Area Index (LAI) estimations. Leaf area was however used to insinuate photosynthetic carbon assimilation and net biomass accumulation efficiency (Watson, 1947). However, this single parameter cannot be used independently to conclude on productivity and growth. The preliminary results of this study document sites restored through participatory forestry activities, and suggest best monitoring practices of established mangrove plantations.

Over 30 community members affiliated to Mombasa Kilindini Community Forest Association (MOKICFA) were trained by Kenya Marine and Fisheries Research Institute. *In situ* training focused on site selection, seed collection and husbandry, species identification and potting of juveniles in plastic materials filled with mangrove substrate. Community members were also trained on subsequent nursery management that entailed pest identification, thinning, gap filling and debris removal. Propagating of nursery hardened propagules was done in April which coincided with the highest seed fall. Seedlings were planted in 1 m x 1 m or 1 m x 0.5 m matrix depending on site convenience. Planting sites were selected in based of tidal inundation regimes, wave action intensity and presence of mature species. Actual planting activities involved seedling transportation, hole preparation and recording the number of individual replanted species. This monitoring expedition collected data on mortality/survival, leaf parameters, height and diameter increment. Nested 10 m x 10 m plots were randomly laid in the plantation perpendicular to the creeks within which mortality/survival, diameter, height, leaf width and length were measured. Tree height was determined using a calibrated pole, stem diameter was measured at 50 cm above the ground using a forester tape, and *Rhizophora mucronata* butt diameter was measured above the last prop root. Leaf width and length were measured using a 30 cm ruler. Derivative of Leaf Area, mean height and diameter class were calculated in Microsoft Excel 2013 spreadsheet.

Results

Participatory forest restocking initiatives of denuded sites are displayed in Table 1.

Table 1. Participatory restoration activities of Mombasa County

Area	Institution	Date Planted	Southing	Easting	Species	No. Seedlings	Area (ha)	Spacing (m)
Mikindani	MOKICFA	Mar-2014	03°59’39.4	039°38’17.0	R m, C t	7,000	0.7	1x1
Mikindani	KMFRI	Apr-2015	03°59’40.1	39°38’20.7	R m	10,000	1	1x1
Mikindani	KKV	Apr-2011	03°59’38.1	039°38’22.7	R m	10,000	1	1x1
Mikindani	Citi-Bank	Jun-2014	03°59’32.4	039°38’10.0	R m	6,500	0.65	1x1
Mikindani	KeMU	Oct-2014	03°59’38.9	039°38’19.7	R m	500	0.05	1x1
Mikindani	WMD	Jul-2016	03°59’43.2	039°38’12.7	C t	210	0.02	1x1
Mikindani	WMD	Jul-2017	03°59’43.3	039°38’16.0	R m, Ct & B g	8,400	0.84	1x1
Mikindani	Big Ship	Apr-2010	03°59’30.9	039°38’07.2	R m	10,000	1	1x0.5
Mshomoroni	B.Y.G	Jun-2012	4^{0}00’31.0	039^{0}40’13.7	R m	15,000	15	1x1
Mwache	KMFRI	Apr-2007	04^{0}01’45.6	039^{0}32’36.8	R m	80,000	8	1x1
Mwache	KMFRI	Apr-2007	04°01’27.2	039°32’22.1	A m	50,000	5	1x0.5

KKV-Kazi Kwa Vijana Project, KEMU-Kenya Methodist University, WMD-World Mangrove Day, B.Y.G-Brain Youth Group.
R m- *Rhizophora mucronata*, C t- *Ceriops tagal*, A m-*Avicennia marina*, B g- *Bruguiera gymnorrhiza*

Establishment and growth varied within different sites. *R. mucronata* of Tudor creek in Mikindani restored by BigShip Community Based Organization (CBO) and Kazi Kwa Vijana (KKV) initiative were relatively adaptable to the site configurations. The BigShip plantation had 95 % survival rate, a height mean of 209 centimeters (cm) and standard error of ±2.48 with a diameter average of 2.8±0.08 cm. KKV plantation in Mikindani had a relatively lower survival rate which was compensated by a higher butt mean of 3.09±0.03 cm and height average of 192.78±0.74 cm. On the other hand, KMFRI plantations established in 2007 of *Avicennia marina* and *R. mucronata* in Mwache creek displayed inferior developmental characteristics.

Table 2. Summary of observed vegetative growth parameters

Lead Institution	Planting Date	Spacing(m)	Species	Survival (%)	Mean Diameter (cm)	Mean Ht(cm)	Mean Leaf Area (cm²)
KMFRI	2007	1x1	R m	56%	2±(0.03)	128±(3.74)	42±(1.42)
KMFRI	2007	1x1	A m	76%	2.26±(0.03)	188±(2.45)	10.42±(0.29)
KKV	2011	1x1	R m	50%	3.09±(0.03)	192.78±(0.74)	52.73±(2.3)
BigShip	2010	1x0.5	R m	95%	2.80±(0.08)	209.44±(2.48)	65.74±(2.01)

Standard Error- Figures enclosed in parenthesis()
A m-Avicennia marina, R m- Rhizophora mucronata
KMFR-Kenya Marine and Fisheries Research Institute
KKV- Kazi Kwa Vijana Initiative

Discussion

Restocking was done using nursery cultured mangrove seedlings due to their previously established high survival rates (FAO, 1994). Substrate suitability, spacing and species suitability were paramount to the establishment and development of the seedlings (FAO, 1994; Kairo *et al.,* 2001; Kimmins, 2004; Kairo *et al.,* 2002).Preliminary assessment of restored sites indicated that height and diameter growth parameters were ideal, convenient and feasible aspects in observing vegetative development and site suitability of established plantations (Watson, 1947). Leaf Area Index, internodes counts and branches could only apply to young plantations that have not been subjected to secondary forestry management practices such as pruning and thinning. *R. mucronata* plantation by BigShip was subjected to pruning limiting application of the aforementioned parameters. So as to maintain consistency and integrity in monitoring, height and diameter parameters were adopted as reliable and accurate vegetative monitoring proxies.

Mikindani plantations were flanked by natural mixed stands of *R. mucronata* suggestive of ideal species selection, which also act as a buffer against direct wave action, maintaining substrate stability and shelter seedlings from direct scotching sun rays. Seedling spacing proved to be a vital factor in influencing growth of closely spaced juveniles. Despite the BigShip plantation displaying superior growth qualities, it was observed that trees increment of height was inconsistent to butt expansion as compared to the KKV plantation that had a 50% survival threshold. There was an observed a shift from facilitation to competition in the spaced stressed plantation, which was observed in dwarf plantation *Avicennia germinans* of Northern Brazil (Pranchai, *et al.,* 2017). This insinuated that poor spacing prevented diameter increment as juveniles competed to outgrow the canopy to deploy leaves to acquire sunlight (Cheeseman, 1994). Comparatively, Mwache creek's inferior growth characteristic could be attributed to poor site configurations due to high terrestrial sediment budgets, low soil moisture and poor hydrological regime (Kairo *et al.*, 2002). High sediment budgets alter tidal inundation, while low soil moisture harden growth substrate causing poor root development hence induce mortality and dwarfism (Kairo *et al.*, 2001 and Duke *et al.*, 2017). Site hydrological regimes and terrestrial sediment budgets characterized by presence of stagnant water pools and high terrestrial sediment influxes could have been responsible for poor growth and establishment of the in Mwache plantations (Bosire *et al.*, 2014).

Conclusion

Growth in degraded sites was subject to spacing, site ecological configurations such as hydrological regime, substrate stability, sediment budgets and soil moisture content. Results from the study suggest that the 2 m x 2 m spacing matrix is best for artificial restocking as proposed by Kairo *et al*. (2001); diameter increment in BigShip *R.mucronata* plantation was constrained by spacing due intraspecific competition for nutrients and space. Tree height and stem diameter were more reliable and consistent parameters in monitoring established plantations. The observed plantations had complex structural properties and were subjected to pruning, therefore determining leaf area index and internode counts was challenging and proved to be unpredictable.

Acknowledgment

Field monitoring and logistics were fund by Punguza Project of Kenya Marine and Fisheries Research Institute under Dr. James G. Kairo as the Principal Investigator.

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Predicting Landscape Changes of the Malewa River Basin, Kenya Under Different Development Scenarios

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Abstract

Predicting future scenarios of landscape change is important in prescribing policy and management actions. This study aimed at predicting land cover change in the Malewa River Basin over a period of four decades (2013-2053). Using land cover data for 1973-2013 to calibrate and validate the model, three landscape change scenarios were modelled using a non-spatial mode of the ST-sim model software. Five land cover classes were modelled, namely cropland, forestland, grassland, shrubland and wetland. The current growth scenario (business as usual) was projected as a continuation of the land transformation rate over the last 40 years. A fast growth scenario assumed a high rate of transformation catalysed by increased population pressure. Conservation scenario assumed improved land productivity without cropland expansion but a likelihood of decreased area under cropland, increase in area under forest and proportionate increase in grassland and shrubland due to optimal utilisation of land. Predictions showed that cropland was likely to increase under business as usual and fast growth scenarios, but stabilized under conservation scenario. Forests would maintain stability under business as usual and conservation scenarios, but drastically decline to less than 30,000 ha under fast growth scenario. It is concluded that business as usual and conservation scenarios are likely to give better results if the right policy and management decisions are pursued. However, fast growth scenario would likely lead to a decline in forest estate and increase in acreage under cropland affecting mainly shrubland and forests land cover classes.

Key words: prediction, scenarios, landscape, land cover, transformation, model

Introduction

Land use changes are mainly attributed to expansion of agriculture and urban areas and extraction of timber and other natural resources. Vegetation cover is thought to increase the capacity of catchments to conserve moisture and increase water yield (Lal, 1997). Land use is integral to agricultural economies, providing substantial economic and social benefits. However, land use changes come at a cost, for example, farmland and forest conversion to urban development reduces the amount of land available for food and timber production, open space and environmental amenities for local residents (Wu, 2008). As a key driver of global environmental change (Turner *et al*., 2007), landscape change is characterized as land conversion into crop and pastoral land in natural systems (Lambin & Meyfroidt, 2011). Land-use change is driven by the interaction in space and time between biophysical and human dimensions (Lambin *et al*., 2002). Historically, intense human utilization of land resources has resulted in significant changes on the land use and land cover (Bronstert *et al*., 2002). Land use change is caused by demographic changes; with migration strongly interacting with government policies, changes in consumption patterns, economic integration and globalization (Lambin and Geist, 2007). According to Perz (2001), Lambin *et al.* (2003) and Browder *et al.* (2004), land use change is a reflection of aggregated land use decisions at the household level (Ebanyat *et al*., 2010). Most tropical deforestation is driven by population pressure for food supplies (Allen and Barnes, 1985). The underlying factors have been aggravated by shifting cultivation and weak national policies (Rudel and Roper, 1996).

The past and present scenarios of landscapes are known through application of technologies such as remote sensing and image interpretation. Analysing and predicting the future requires deployment of appropriate modelling methodologies. Some of the approaches have attracted increased policy interest, an example being a policy directive issued by the European Commission in 2000 (European Commission, 2003) on modelling freshwater basins. However, environmental models generally lack appropriate economic system models (Brouwer and Hofkes, 2008). Despite the limitations, a few integrated modelling studies have combined biophysical modelling tools with economic valuation techniques in a robust framework to guide natural resource management decisions (Croke *et al*., 2008). The Monte Carlo approach has been successfully used in a Uganda study (Berger and Schreinemachers, 2006).

State-and-transition simulation models (STSM) have evolved over the years. ST-sim, one of a set of STSM (Daniel and Fried, 2011; Daniel *et al*., 2016) evolved from Markov chains. This is a form of stochastic, empirical simulation model used to predict the transition of vegetation between states over time, in response to the interactions observed between succession, disturbances and management. It is strongly empirical, stochastic, and is able to model at stand (acreage) and regional levels. In addition, it can be run in spatial and non-spatial modes, and is flexible in application across ecosystems. STSM is simple and flexible, allowing the use of imperfect knowledge, parameterization using expert opinion, and the possibility to simulate multiple scenarios under different levels of uncertainty (Daniel and Fried, 2011).

Landscape change detection methodologies can be used to establish the past and current status of land cover. However, information on future change scenarios in land cover is lacking in the study area. As such, it is difficult to institute policy and strategic management responses to address the issues impacting on land use and land cover change. Landscape scenario modelling is proposed to provide a solution to the lack of data and information for decision making. The aim of this study was therefore to predict likely scenarios of land cover change in the Malewa River Basin in Kenya. The study site was selected based on the premise that previous studies have tended to concentrate on the lower catchment rather than upper catchment. There has therefore been limited efforts towards the understanding the factors driving the environmental problems experienced that includes land use and land cover changes and subsequent effects on stream flows.

Methods

Study area

The Malewa River Basin (1,760 km^2) is located in the larger Lake Naivasha Basin within Nakuru and Nyandarua Counties of the Eastern African Rift Valley (Gregory), Kenya (at 36^0 05' E - 36^0 42' E longitudes and 00^0 07' S - 00^{0}45'S latitude). See Figure 1. The Malewa River has a dendritic drainage system with four main streams namely the Turasha, Kitiri, Mugutyu and Makungi. Agriculture, grassland, bush/scrub land and forest are the major land cover types (Ogweno *et al*., 2010). Forests and cropland dominate the land use in the upper catchment, and livestock keeping is practised at the lower catchment (Muthawatta, 2004).

Land cover change detection

The land cover change for the study area was determined using satellite image analysis. Images from Landsat MultiSpectral Scanner (MSS) (1973), Landsat Thematic Mapper (TM) (1986) and Enhanced Thematic Mapper Plus (ETM+) (2000) obtained from the Landsat database (orthorectified archives) (NASA, 2015) were geo-processed using ERDAS imagine 2015 and ArcGIS 10.1 software. Pre-processed SPOT image from Astrium was used. Image analysis techniques applied included co-registration (ERDAS Inc, 2008; Barazzetti *et al*., 2014), image differencing (ERDAS Inc, 2008; İlsever & Unsalan, 2012), threshold based segmentation (Dey *et al*., 2010; Telgad *et al*., 2014) and accuracy assessment (Congalton, 1991; Abubaker *et al*., 2013). Image interpretation tools available in ERDAS imagine 2015 were used to perform image processing and enhancement. An object-based classification of images based on a supervised maximum likelihood classification technique was used. The classification scheme adopted was that of Anderson *et al*. (1976) resulting in six distinct classes namely cropland (horticulture and rain-fed agriculture), forestland (natural forests, woodlots and forest plantations), wetland (open waters and swamps/marshes), shrubland and settlement.

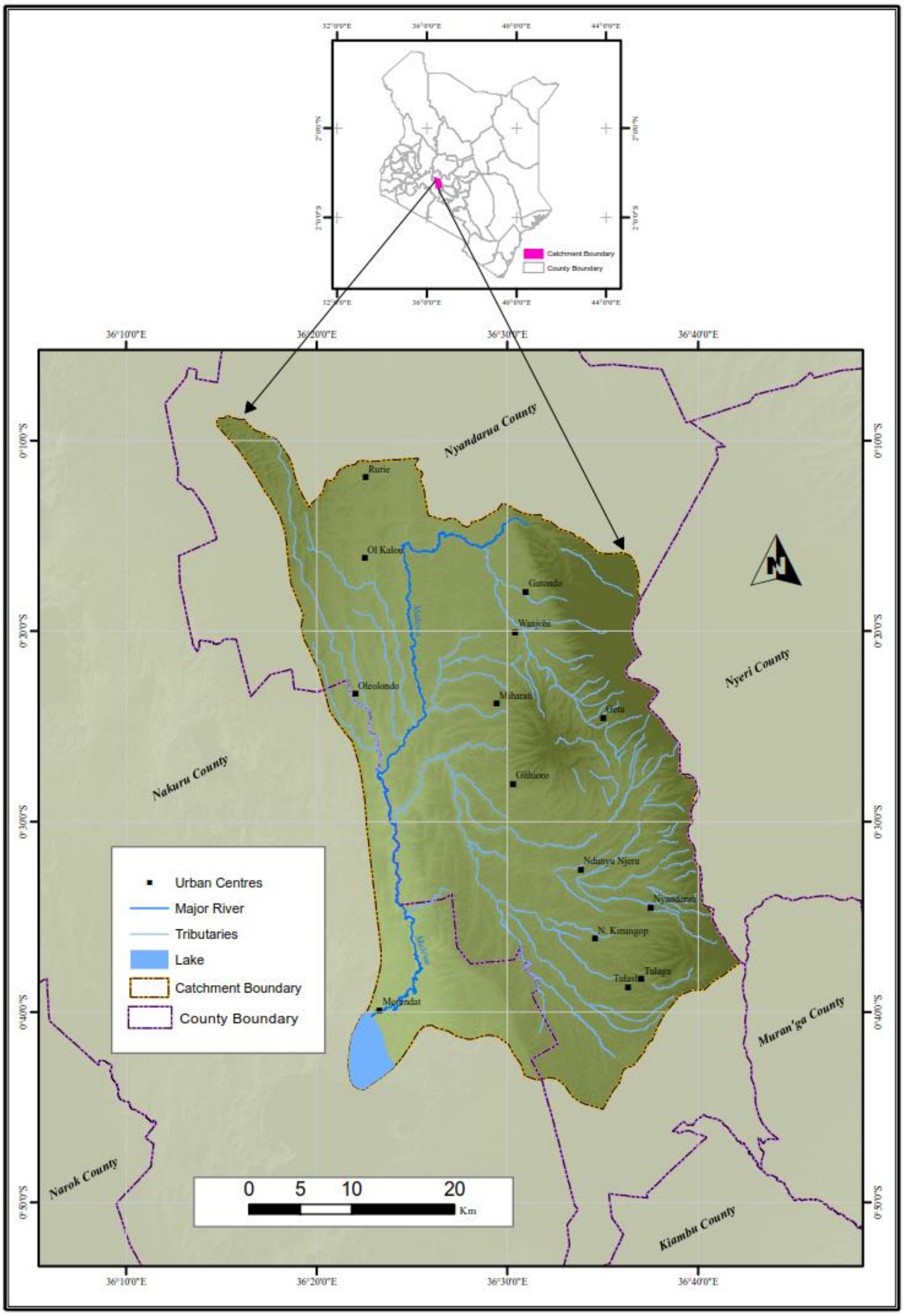

Figure 1. Map of the study area

Land cover scenario modelling

Using land cover data (1973-2013) from the land cover change detection above, three landscape change scenarios were modeled using the non-spatial mode of the ST-sim software. Current growth scenario (business as usual) was projected as a continuation of the land transformation rates over the last 40 years. In this scenario, it was assumed that cropland would increase, while forestland, shrubland and wetlands would remain stable. The human population density would increase. The fast growth scenario assumed a high rate of transformation with increased area under cropland, decrease in forestland and proportionate changes on grassland and shrubland. Conservation growth scenario assumed improved land productivity without cropland expansion. However, there would be a likelihood of decreased area under cropland, increase in area under forest and proportionate increase in grassland and shrubland. Conservation activities would intensify including farm forestry, land management and increased protection of government forests. The young population would likely venture into non-land based enterprises.

Five land cover classes were modeled namely cropland, forestland, grassland, shrubland and wetland. To ensure consistency with 1973 land cover map, areas under forest plantations, woodlots and indigenous forest identified in 2013 land cover map (based on high spatial resolution image) were merged into forestland class. Settlement and horticulture which are negligible in size were combined with areas under cropland. The model was set by establishing the different forms of transition pathways, which reflected what was observed in the land cover changes for the years examined. In these pathways, the model identified two types of transitions: deterministic and probabilistic (Daniel *et al*., 2016). Deterministic transitions are transitions from one class to another. Probabilistic transitions refer to the likelihood that change would occur from one land cover to another and over a specific time frame (age). Initial conditions were established by setting the total area to be modeled and defining the number of simulation cells and their sizes. Of the 176,415.1 ha used, 100,000 cells were defined giving an average cell size of 1.7642 ha. Five transition groups (types) were defined, that were assumed to mirror the land cover change processes in the study area. These were agricultural expansion, fires, harvest, restoration and succession. The land cover data (1973-2013) was then used to calibrate and validate the ST-sim model. Initial estimates of change elasticity, following their transition trends, were generated to define transitional probability. The estimated probability was adjusted through a trial and error approach until a realistic prediction was achieved. This was verified using visual observation by comparing with the generated data, and was also subjected to a t-test for validation. The stochastic conditioning of the model was set at 40 iterations for all transitions and automatically run at 95 percent probability.

Results

Changes in land cover of the study area

The study area experienced transitions in cropland with a growth of 28.8 % (25,616.9) over the four decades. Similarly, forestland increased by 11.3 % (4,310.3 ha) while wetland increased by a record 490.4 % (688.0 ha). Shrubland however declined by 72.2 % (28,953.8 ha) and grassland 19.2 % (1,747.5 ha). The land cover changes in the study area are provided in Table 1.

Table 1. Land cover changes in the study area

Year	Cropland	Forestland	Grassland	Shrubland	Wetland
1973	88,834.9	38,221.1	9,124.1	40,095.0	140.2
1986	94,430.6	35,556.7	23,321.8	22,724.9	334.3
2000	102,604.8	33,748.9	4,625.0	35,097.9	291.5
2013	114,451.8	42,531.2	7,376.7	11,141.1	828.2

Model calibration and validation

The five land cover types modelled are summarised in a model transition pathway (Figure 2). From this diagram, it is clear that all land cover types experienced both deterministic and probabilistic changes from one type to another over a period of time.

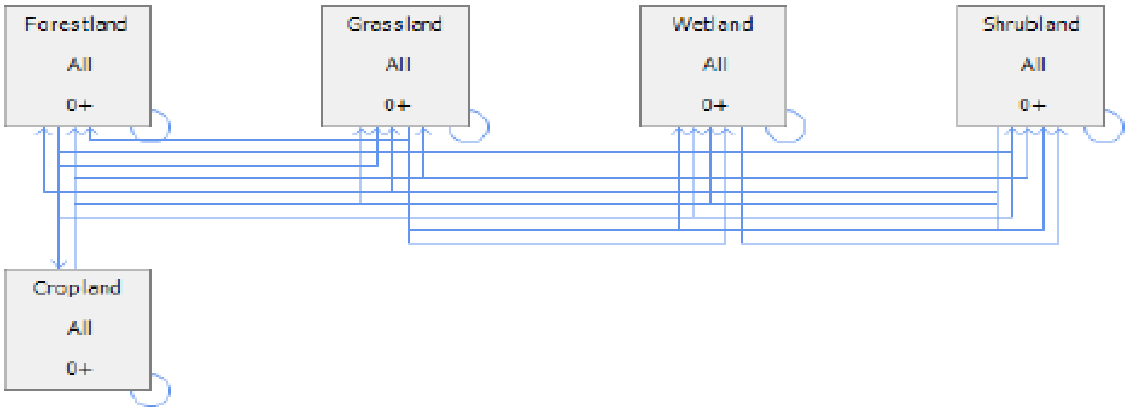

Figure 2. Land cover transition pathways applied in ST-Sim model

A paired sample t-test showed that cropland calibrated and observed values were strongly correlated (*r*=.956, *p*=.000). There was significant difference in calibrated (*M*=102,991.6, *SD*=8,727.5) compared to observed values (*M*=99,302.0, *SD*=7,433.5); *t*(40)=8.707, *p*=.000). Forestland calibrated values were moderately correlated with observed values (*r*=.435, *p*=.000). A significant difference was found on calibrated values (*M*=38,030.9, *SD*=57.7) compared to observed values (*M*=36,030.9, *SD*=2,120.0); *t*(40)= 5.928, *p*=.000). Grassland calibrated values were negatively correlated with observed values (*r*=-.697, *p*=.030). There was significant difference in calibrated values (*M*=9,300.4, *SD*=48.2) compared to observed values (*M*=12,536.0, SD=9,161.3); *t*(40)= -2.253, *p*=.030). Shrubland calibrated values were not correlated with observed values (*r*=.060, *p*=.711). However, there was a significant difference in calibrated (*M*=17,553.1, *SD*=6,110.6) compared to observed values (*M*=28,085, *SD*=5805.0); *t*(40)= -8.251, *p*=.000). Wetland calibrated values were weakly correlated with observed values (*r*=-.326, *p*=.037). There was significant difference in calibrated (*M*=8,539.0, *SD*=4971.1) compared to observed values (*M*=353.5, *SD*=131.2); *t*(40)= 10.450, *p*=.000).

Predicted cropland changes (2013-2053)

Under the business as usual (BAU) scenario (i.e. the current status), cropland was predicted to increase by 4.2 % and 6.7 % during 2033 and 2053, respectively. Based on a fast growth scenario, the model predicts 16.4 % in 2033 and a dramatic increase of 20.3 % in 2053. The conservation scenario will however have minimal changes with 0.5 % increase in area by 2033 compared to 0.7 % by 2053. The predicted absolute and percentage changes in land cover under cropland from 2013 to 2053 are shown in Table 2

Table 2. Predicted landscape change scenarios (2013-2053)

Scenarios	2013	2033			2053		
	Area (ha)	Area (ha)	Absolute	%	Area (ha)	Absolute	%
BAU	114,473.8	119,290.3	4,816.5	4.2	122,169.8	7,695.9	6.7
Fast growth	114,556.6	133,374.0	18,817.4	16.4	137,840.0	23,283.4	20.3
Conservation	114,589.3	115,159.2	569.9	0.5	115,403.3	813.9	0.7

The predicted changes based on the three scenarios are graphically represented in Figure 3 below. As demonstrated by this graph, a fast growth scenario will see an increased expansion in cropland. BAU scenario will likely see a moderate growth in cropland, while conservation scenario will be stable at the current level.

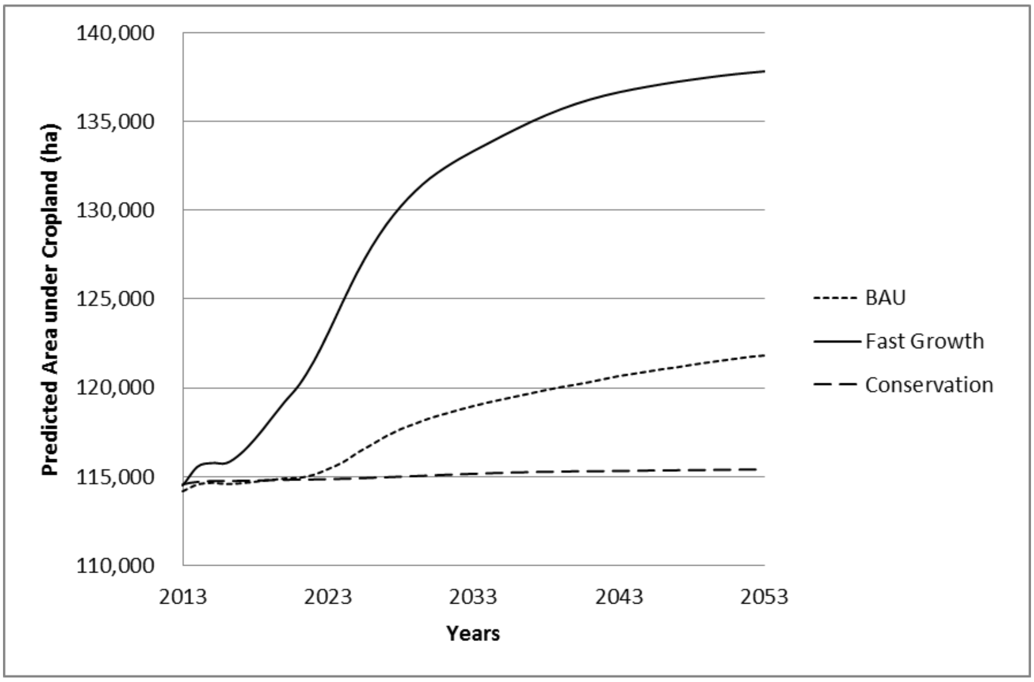

Figure 3. Predicted changes in area under cropland

Predicted forestland changes (2013-2053)

From a baseline of 42,572 ha, BAU case scenario predicts forestland to reduce by 0.5 % at the close of 2033, and a similar figure by 2053. A fast growth scenario would likely see a significant reduction of 31 % during the two periods. Conservation scenario will likely have minimal change of 0.7 % in both 2033 and 2053. Both the business as usual and conservation scenarios will likely maintain a stable trend in area under forest estimated at about 42,000 ha. However, the fast growth scenario will likely have a drastic decline (31.1 %) to less than 30,000 ha (Table 3).

Table 3. Predicted changes in area under forestland

Scenarios	2013	2033			2053		
	Area (ha)	Area (ha)	Absolute	%	Area (ha)	Absolute	%
BAU	42,571.7	42,349.9	(221.8)	-0.5	42,349.9	(221.8)	-0.5
Fast growth	42,517.7	29,309.6	(13,208.1)	-31.1	29,309.6	(13,208.1)	-31.1
Conservation	42,477.8	42,167.9	(309.9)	-0.7	42,167.9	(309.9)	-0.7

The predicted changes in forest area under the three scenarios are illustrated in Figure 4. As shown by this graph, there will be a stiff curve under a fast growth scenario over the next ten years before this trend stabilises. Both BAU and conservation scenarios are stable at slightly over 42,000 ha.

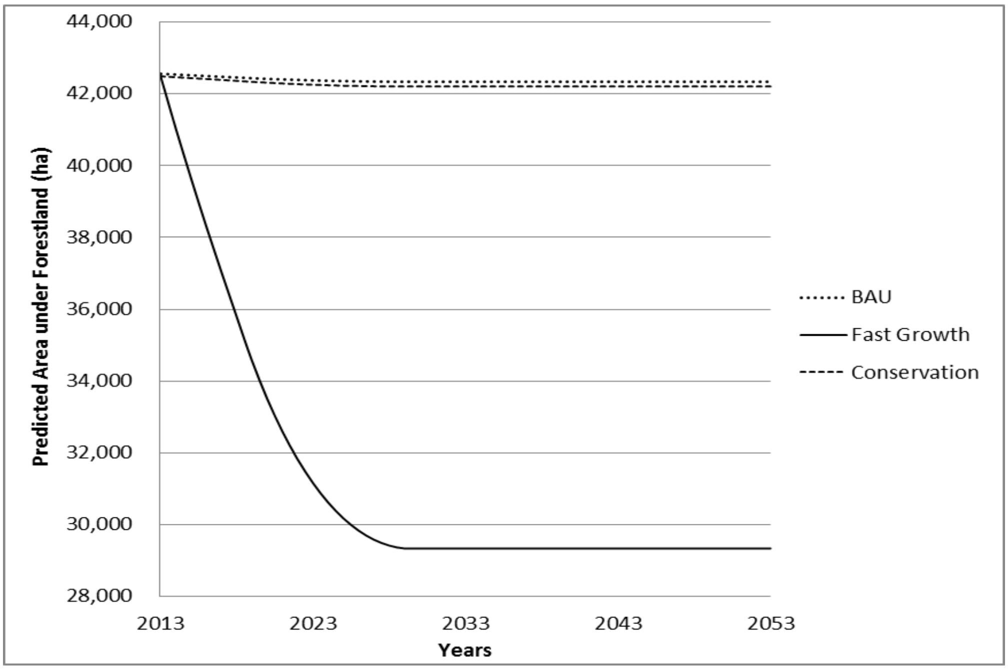

Figure 4. Predicted area under forestland

Predicted grassland changes (2013-2053)

Grassland will have a minimal increment of 2.1 % in 2033 and 2.3 % in 2053 under the BAU scenario. Under fast growth scenario, the changes will even be lower at 0.3 % in both cases. Conservation scenario will have no change in area under grassland. Grassland will take a stable trend of about 7,000 ha (Table 4).

Table 4. Predicted changes in area under grassland

Scenarios	2013 Area (ha)	2033 Area (ha)	Absolute	%	2053 Area (ha)	Absolute	%
BAU	7,353.5	7,510.8	157.3	2.1	7,525.7	172.3	2.3
Fast growth	7,376.9	7,397.5	20.6	0.3	7,399.4	22.5	0.3
Conservation	7,367.4	7,367.4	-	0.0	7,367.4	-	0.0

The predicted changes in area under grassland under the three scenarios are shown in Figure 5. According to this graph, grassland will be affected by land use changes experienced at the current state although the magnitude of change will likely be insignificant in absolute terms.

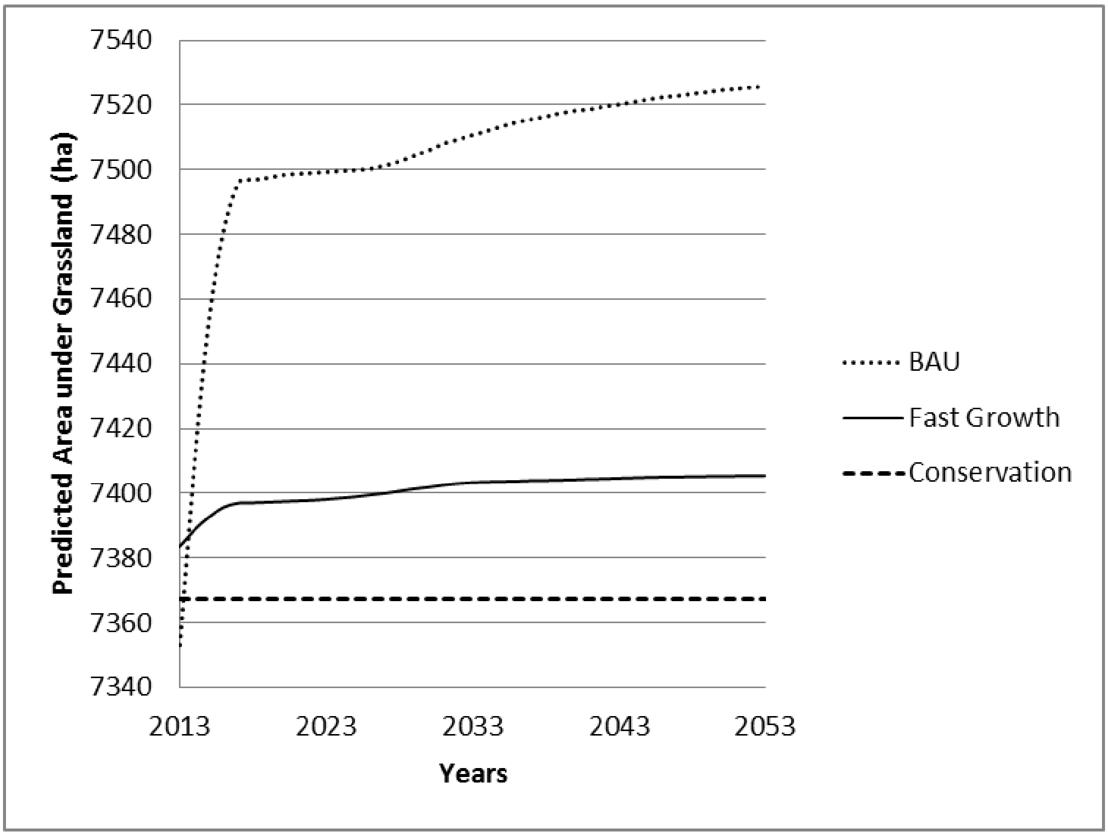

Figure 5. Predicted area under grassland

Predicted shrubland changes (2013-2053)

Under BAU scenario, there will likely be a drastic change in area under shrubland, with 57 % lost by 2033 and 72 % in 2053. A fast growth scenario will have a reduction of 73 % and 95 % in 2033 and 2053, respectively. It appears that shrubland is more prone to the effects of external pressures than other land cover classes. Conservation scenario will have a minimal reduction of 3 % in both cases. Area under shrubland will likely remain stable under conservation scenario, but decline under both BAU and fast growth scenarios (Table 5).

Table 5. Predicted changes in area under shrubland

Scenarios	2013 Area (ha)	2033 Area (ha)	Absolute	%	2053 Area (ha)	Absolute	%
BAU	11,185.1	4,847.8	(6,337.4)	-56.7	3,123.6	(8,061.5)	-72.1
Fast growth	11,127.9	2,994.6	(8,133.3)	-73.1	508.1	(10,619.8)	-95.4
Conservation	11,155.4	10,818.1	(337.3)	-3.0	10,825.6	(329.8)	-3.0

The trends are graphically shown in Figure 6. As shown in the graph, the changes in both fast growth and BAU scenario are likely to be significant after ten years. By 2053, it is unlikely to have shrubland remaining in the study areas if the trend continues. However, a conservation scenario will likely see stability in area under shrubland over the next 40 years.

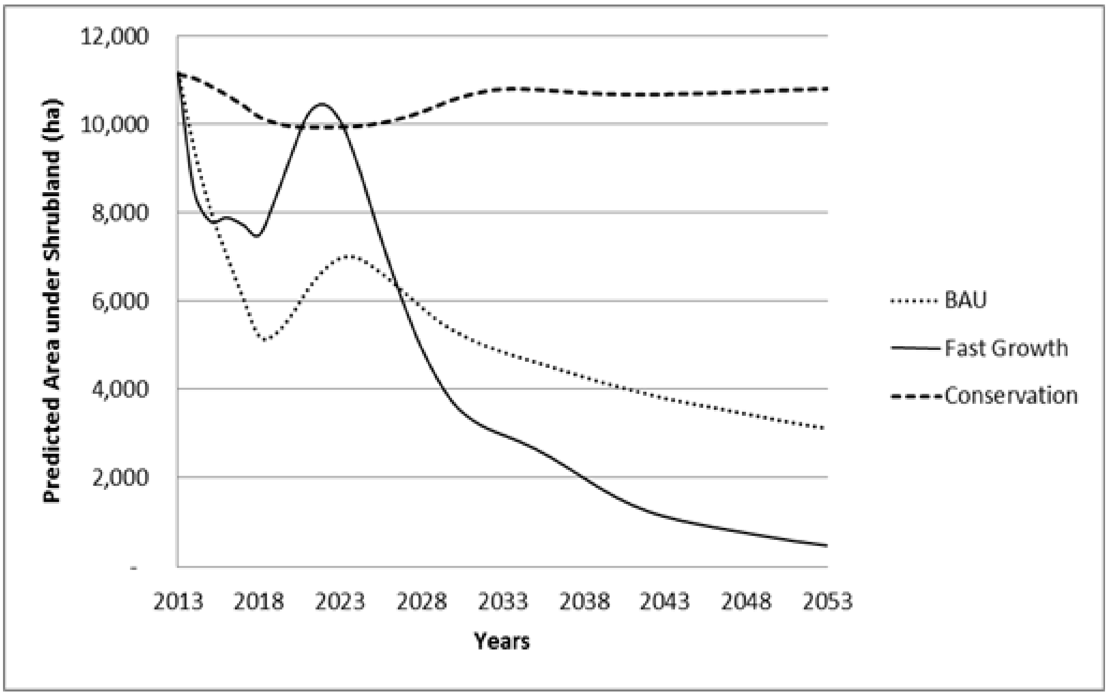

Figure 6. Predicted area under shrubland

Predicted wetland changes (2013-2053)

The predicted changes in wetland are shown in Table 6. Wetlands will likely increase under BAU scenario by 191 % by 2033 and 50 % by 2053. A fast growth scenario will likely increase the area under wetland by 299 % and 62 %, respectively. Wetlands ae very unstable ecosystems and if subjected to enormous pressure, this can likely change rapidly, particularly as influenced by factors such as land suitability, changes in climatic regime and human related drivers. A conservation scenario will likely increase the area under wetland by 9 % by 2033 and a reduction of 21 % in 2053.

Table 6. Predicted changes in area under wetland

Scenarios	2013	2033			2053		
	Area (ha)	Area (ha)	Absolute	%	Area (ha)	Absolute	%
BAU	831.0	2,416.3	1,585.3	190.8	1,246.1	415.1	49.9
Fast growth	836.0	3,339.4	2,503.3	299.4	1,358.0	522.0	62.4
Conservation	825.2	902.5	77.3	9.4	651.0	-174.2	-21.1

Area under wetland is likely to increase over the next 10 years and thereafter decline in all scenarios (Figure 7).

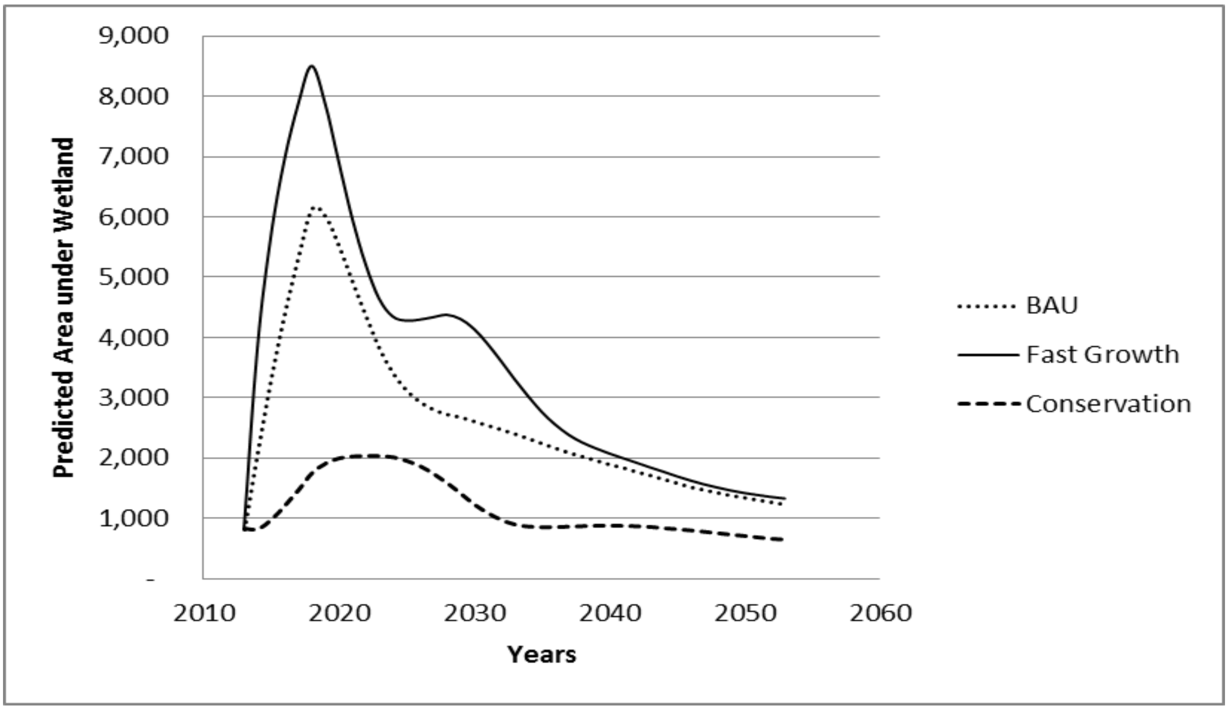

Figure 7. Predicted area under wetlands

Discussion

Prediction of land cover change is a complex process usually marred with uncertainties. As suggested in Müller *et al.* (2014), land systems are subject to periods of nonlinear and abrupt change that may invalidate predictions calibrated on past trends. Indeed, the predictability of land system change is limited by regime shifts, which occurs when critical thresholds in broad-scale underlying drivers are surpassed. Examples of drivers include change in commodity prices, climate conditions or natural disasters. It is important to establish clear baselines to benchmark land cover changes. As such, land cover change detection provided insights of trends over the last 40 years. This is because the current situation would likely shape the events and status over next four decades. Model selection is a key determinant to increasing the likelihood of model success, and minimizing errors and omissions. There are uncertainties in evaluating results of the model related to rapid changes over the set timeframes, accuracy of data and inability to control drivers of change. Overall, calibrated and validated model outcomes roughly matched, thus indicative of improved robustness and reliability of the model results.

The model prediction results on cropland seem to suggest that BAU and conservation scenarios are better options, for their minimal changes. This emphasizes the need to manage the drivers of land cover change, and at least mitigate to reverse from the current change levels. The BAU and conservation scenario options are better pathways to follow due to their minimal damages on the forest estate. The drivers of forest cover change require mitigation. The prediction suggests that grassland is the most stable land cover type, and its growth is negligible. This is likely because of their resilience to changes in climatic conditions, soil and water retention abilities and seedbanks. Shrubland is the most unstable land cover type with a perpetual negative growth, in all scenarios. Conservation scenario will likely save the situation from the current declining trends. Shrubland is a likely target for conversion to cropland and settlement. The changes in wetlands seem to be determined by factors such as land suitability, changes in climatic regime, and human related drivers. In all scenarios, area under wetland surprisingly increased to a certain optimum over a decade, and then rapidly declined over the remaining model time.

The predicted changes in the study area are not much different from that happening elsewhere. In a land use demand simulation in Beijing China, rapid urbanization processes were found to likely result in cultivated land converted to urban built-up, and therefore assume a future landscape change. The change was more likely to be serious in mountainous areas, because these regions are important barriers and water conservation areas and the high altitude limits urban expansion (Han *et al*., 2015). In Long Island Sound Watersheds in the New England region, model results showed an increase in developed area (urban expansion) and decrease in forest, with the loss attributed to low density development pattern. Distance to developed areas, distance to roads and socio-economic drivers (including nighttime light intensity and population density) were contributing factors to the change (Zhai *et al*., 2016). Using an econometric model projected over 40 years in North China Plains, simulation results under different scenarios (business as usual, rapid economic growth and coordinated environmental sustainability scenarios) showed that land use structure changes would transfer from cultivated to build up area, have an increase in forestry and decrease in grassland. The change would likely be driven by urbanization due to demographic changes (Zhan *et al*., 2013).

These findings also agree with the results of scenario modelling in the Upper Blue Nile River (2009-2025) that indicated that agricultural expansion would continue to expand, in this case from 69.5 % in 2009 to 77.5 % in 2025. However the growth rate of plantation forest would be much higher, expanding into natural vegetation, agricultural land and grassland (Yalew *et al*., 2016). Modelling results in Igneada, Turkey showed a constant but overall slight increase of settlement and forest cover as well as a light decrease of agricultural lands (Bozkaya *et al*., 2015). Prediction of land use classes (forest/range, crop/pasture, urban) surrounding the U.S Fish and Wildlife Service's National Wildlife refuges by 2051 indicated an increase in forest/rangelands (by 1.9 % to 4.7 %), an increase in crop/pasture (15.2 % to 23.1 %) and a substantial increase in urban land use (28.5 %-57 %). Effectively influencing land use change patterns using national policies would be rather difficult. A better understanding of regional land use dynamics was recommended to inform effective management and planning of protected areas (Hamilton *et al*., 2013).

Conclusions

The model prediction showed that even under current conditions, cropland and shrubland will increase. Cropland and forestland under a fast growth scenario will drastically increase. A conservation scenario would be a best compromise, with minimal changes under the different land cover classes. This study has found that both BAU and conservation scenarios provide better prospects to manage landscape change in the study area. While the drivers of change are widely known, this needs to be contextualized within the study area. A combination of both policy and strategic efforts is likely to provide the solutions. There is therefore a need to institute measures that reconcile the different land uses, and therefore achieve a sustainable land cover state.

It is becoming apparent that scenario planning is one strategy that could likely help mitigate losses associated to land cover change. Participatory scenario planning is recommended to manage different stakeholder expectations on land use. Expansion of cropland and mitigation of losses on shrubland and forest requires intensifying sustainable agricultural production. This is by implementing a scheme of optimal land use and applying sustainable land use practices such as agroforestry, planting of cover crops and woodlots. In this planning, a careful process to understand natural and anthropogenic drivers, at relevant scale, is likely to inform decisions to effectively manage the changes. There is also need to undertake farm level land use and scenario planning studies as a strategy to inform decision on land management.

Acknowledgement
We are grateful to WWF Kenya, Astrium and National Aeronautics and Space Administration for the use of satellite images. Thanks go to ESRI and Apex Resource Management Solutions Ltd for the use of analytical software. We would like to thank Mr. Zachary Maritim, Mr. Reuben Soy, Ms.Winfred Manetu and Mr. Liya Mango for their assistance in mapping and modelling methodologies.

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Variation in Floral and Structural Composition of Vegetation under Controlled Resource Use and Exclusive Resource Conservation in Mt. Elgon Forest Ecosystem

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Abstract

Debate has emerged on whether to revert to exclusive resource conservation to restore degraded forests ecosystems rather than placing them under community-based management. In this study, the floristic composition and stand structure of a forest reserve and a national park that are located within the same vegetation zones in Mt. Elgon Forest Ecosystem were assessed. A nested experimental design was adopted with the vegetation zones serving as assessment blocks and the two conservation approaches serving as sub-blocks in each of the blocks. The results indicated that the forest reserve had double the species diversity of the national park. The national park had a higher stem density (125.7 ± 5.2 stems ha^{-1}) than the forest reserve (89.3 ± 18.3 stems ha^{-1}), but the mean DBH of its stems was much smaller (32.4 ± 1.8 cm) than that of the forest reserve (46.0 ± 1.48 cm), which suggested that trees of the national park were younger than those of the forest reserve. The mean canopy height of the forest reserve was higher (30.7 ± 2.0 m) than that of the national park (19.5 ± 1.9 m). It was interesting to find that trees of the national park were not only younger but also shorter. This indicated that the floristic and structural integrity of Mount Elgon Forest Ecosystem was better in areas within the forest reserve than the national park. The community-based conservation approach can nevertheless be strengthened by defining permissible resource off-take thresholds beyond which resource exploitation should not exceed.

Keywords: Sustainable forest management, resource use, conservation

Introduction

In many parts of the world, forest ecosystems are managed either as forest reserves or national parks. In some cases, one forest ecosystem is sub-divided into a forest reserve and a national park. The forest reserves and national parks are created to protect the ecological integrity of forest ecosystems in order to secure their environmental and socio-economic functions (Muhumuza and Balkwill, 2013). The management of forest reserves often follows the community-based conservation approach, which allows forest adjoining communities to derive socio-economic benefits from such forests through controlled resource use (Stolton ***et al***., 2010). The management of national parks, on the other hand, often follows the protectionist preservation approach, which excludes any form of resource utilization by communities inside the park (Schroeder, 1999). Proponents of the preservation approach argue that exclusive resource conservation secures human lives by eliminating human-wildlife conflicts. In Kenya, however, community-based conservation of forest reserves is barely a decade old (Republic of Kenya, 2005). For a long time, forests were managed under the protectionists approach, commonly referred to as the command and control approach. The situation changed with the enactment of the Forest Act of 2005, which provided for community participation in forest management (Republic of Kenya, 2005).

Although largely popular with key stakeholders in forest management, the community-based conservation approach has failed to realize sustainable forest management in most parts of the developing world (Butchart *et al*., 2010;Muhumuza and Balkwill, 2013).The Convention on Biological Diversity's global outlook 3 report of 2010 indicates that forest ecosystems have continued to lose biodiversity even under very well-intended community-based conservation arrangements (Secretariat of the Convention on Biological Diversity, 2010). Some of the indicators of unsustainable forest management under the community-based conservation approach include decrease in forest cover, decline in the population of certain species of plants and animals, overexploitation of forest resources and emergence of invasive plant species, especially in areas where forest cover has been lost (Butchart *et al*., 2010; Rands *et al*., 2010). Opinion is presently divided whether to address challenges facing the community-based conservation approach through legal and policy instruments or to simply revert to the protectionist preservation approach byexcluding external interference offorest ecosystems. This debate has been stimulated partly by the fact that a casual look at the forest cover in national parks reveals a relatively more intact and pristine environment than in adjacent forest reserves. Visual assessment is, however, not a good indicator of ecosystem integrity and cannot be relied upon to inform policy debate on how to address challenges facing conservation strategies in forest reserves.

Studies have been carried out on the merits and demerits of both community-based conservation and preservation approaches(Bruner ***et al***., 2001; Kiringe *et al*., 2007), but very few, if any, have compared the floristic composition and structural characteristics of forest reserves and national parks that are located within the same forest ecosystem. There is, therefore, scarcity of evidence to guide decision making on which of the two conservation approaches is more effective to deliver sustainable forest management or how any of the two can be improved. The objective of this study was to compare the floristic composition and structural characteristics of a forest reserve and national park in Mount Elgon Forest Ecosystem. The two conservation areas fall within the same ecological and altitudinal zones. The national park was gazetted in 1968 and covers 16,900 ha of the montane forest, holding different species of wildlife under the protectionist exclusive resource preservation approach. The forest reserve was gazetted in 1932 and covers 73,705 ha of the forest. It is managed through the community-based conservation approach, which provides for controlled use of forest resources. Findings of this study are expected to provide insight to the on-going debate on the role of community-based versus exclusive resource conservation in the preservation of forest ecosystem integrity and resilience.

Materials and Methods

Study area

The assessment was carried out within Mount Elgon Forest Ecosystem in May 2017. The forest ecosystem is an afro-montane forest located in western Kenya between latitudes 1^{o} 08′ 00″ N and longitudes 34^{o} 33′ 00″ E at an elevation of between 2,200 m and 4,222 m above sea level (Mwaura, 2011). The area has a cool and moist climate characterized by a mean temperature of 16^{o}C. It receives a bimodal rainfall of between 1,500 mm and 2,000 mm per year with dry seasons between June and August and December and March (MUIENR and NMK, 2005). There are four forest vegetation zones from the slopes of the mountain to its peak, namely: a mixed montane forest, bamboo low-canopy forest, sub-alpine montane heath, and alpine moorland. The ecosystem comprises a forest reserve and a national park, both of which fall within the four vegetation zones. The upper zones of the forest reserve support an indigenous forest-dwelling community, which relies on livestock production (MUIENR and NMK, 2005). The lower zones support forest adjoining farming communities, whose population density is currently estimated at about 600 persons per km^2 (Petursson *et al*., 2006). Some of the resources that communities obtain from the forest include herbal medicine, fuel wood, pasture for livestock, timber, construction poles, fibre, and indigenous fruits and vegetables (Scott, 1994).

The mixed montane forest on the mountain slopes is primarily covered with Elgon olive *(Olea capense)* and *Aningeria adolfi-friedericii*, while the bamboo low-canopy forest comprises mainly giant *Podocarpus spp*, *Yushania alpina* and many orchids (Bakamwesiga *et al*., 2005). There is a transition zone between the bamboo vegetation and the sub-alpine montane heath, which comprises a dense mixed stand of rosewood (*Hagenia abyssinica),* cedar (*Juniperus procera),* pillarwood (*Cassipourea malosana)* and elder trees (*Sambucus adnate*) (Tweedie, 1975). The sub-alpine montane heath and the alpine moorland are covered with *Erica arborea* and *Philippia trimera*, tussock grasses such as *Agrostis gracilifolia* and *Festuca pilgeri*, herbs such as *Alchemilla spp.*, *Helichrysum spp.*, *Lobelia spp.*, and the giant groundsels *Senecio barbatipes* and *Senecio elgonensis* (Howard, 1991).

Study design

The assessment employed a nested experimental design. It was carried out in three vegetation zones, namely: the mixed montane forest, bamboo low-canopy forest and sub-alpine montane heath, which served as assessment blocks. Since the forest reserve and the national park occupied all the three assessment blocks, they served as the sub-blocks of this assessment. Assessment was done using line transects in each vegetation zone. Three transects of 1 km each were laid across a sub-block. Sampling involved stratified systematic sampling. Sample plots of 20 m by 10 m were laid at intervals of 300 m along each transect. The 20 m by 10 m main plot was used to assess woody plants ≥ 10 cm in diameter at breast height (DBH). A 5m by 5m sub-plot was nested within the main plot and used for assessing saplings, shrubs and lianas of DBH 2.0 cm - 9.9 cm. Grass and other herbaceous plants were assessed in 1 m by 1 m sub-plots, also nested within the 20 m by 10 m plot.

Data collection
Data were collected on plant species, stem diameter at breast height (DBH) and canopy height of woody plants. Counts were made of saplings, seedlings and erectile herbs. Estimates were made of the percentage ground cover of grass and creeping herbs.

Data analysis
The data collected were used to derive plant species richness, species diversity and evenness, stem density, basal area and mean canopy height. Species diversity was calculated using the Shannon diversity index, while species evenness was calculated using the Simpson index (Magurran, 2004). The data were analyzed using Genstat statistical software version 17 (VSN International, 2016).Analysis of variance was carried out to test for significance of the variation in plant species diversity, stem density, basal area and canopy height between the forest reserve and the national park at 5% significance level.

Results

Floristic composition

Species richness, diversity and evenness
The forest reserve had a higher species richness than the national park (Table 1). The number of plant species in the national park was about half that of the forest reserve. The forest reserve had also had a significantly higher species diversity and species evenness than the national park.

Table 1. Species richness, diversity and evenness in the forest reserve and national park in Mount Elgon Forest Ecosystem

Forest area	Species richness	Species diversity (Shannon index)	Species evenness (Simpson index)
Forest reserve	93	$2.274 \pm 0.130_{b}$	$0.231 \pm 0.035_{b}$
National park	47	$0.719 \pm 0.129_{a}$	$0.024 \pm 0.002_{a}$
p value		0.009	0.032
l.s.d.		0.724	0.154

Woody species richness and associations in vegetation zones
A comparison of woody species richness across vegetation zones indicated that the forest reserve and the national park had similar woody species richness within the mixed montane forest. However, the forest reserve had a higher woody species richness than the national park in the bamboo low-canopy forest (Figure 1). The forest reserve had also more woody species in the sub-alpine montane heath than the national park, which was largely grassland in this vegetation zone (Figure 1).

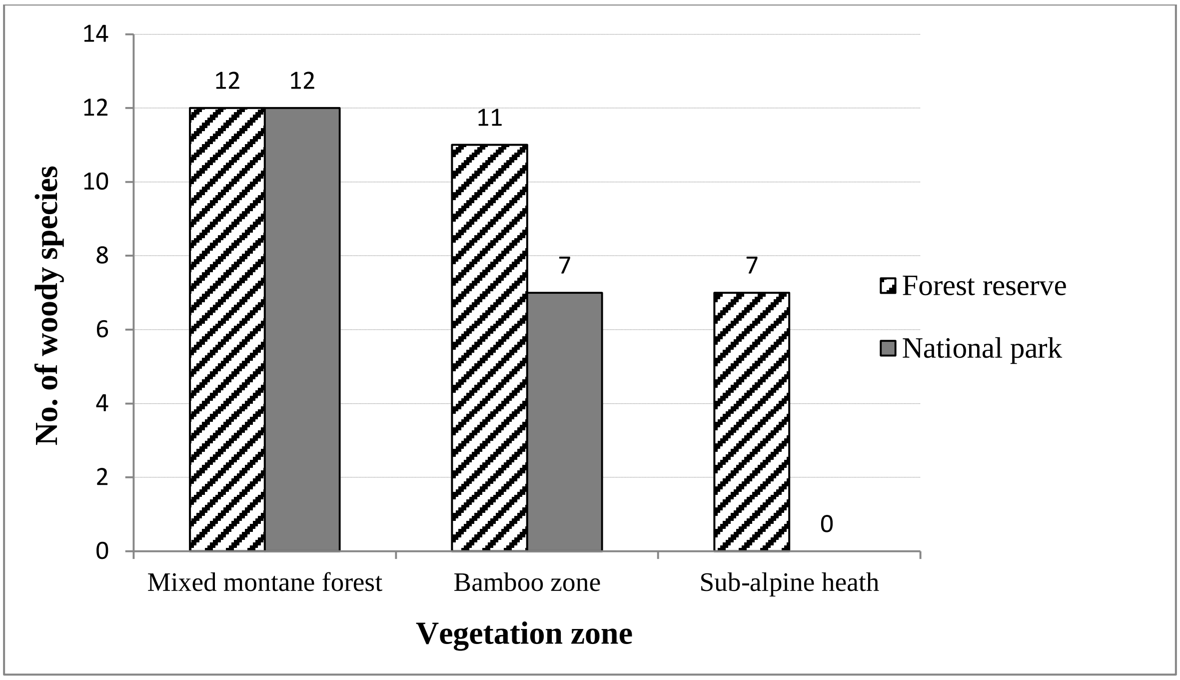

Figure 1. Woody species richness in the forest reserve and national park in Mount Elgon Forest Ecosystem in May 2017.

Analysis of woody species associations indicated that *Neoboutonia macrocalyx* and *Casearia battiscombei* were the most abundant in the forest reserve within the mixed montane forest (Table 2). *Ekebergia capensis*, *Aningeria adolfi-friedericii* and *Celtis africana* were also represented in large numbers. In the national park, *Ficus thonningii* and *Podocarpus falcatus* were the most abundant in the mixed montane forest, but the populations of *Croton microstachyus*, *Olea europea* subspecies *caudata* and *Trichocladus ellipticus* were also comparatively large. In the bamboo zone, *Podocarpus latifolius, Bersama abyssinica* and *Neoboutonia macrocalyx* were the most abundant woody species in the forest reserve. The national park had *Podocarpus falcatus* and *Dovyalis abyssinica* as the most abundant woody species in this vegetation zone (Table 2). In the sub-alpine montane heath, *Juniperus procera, Erica arborea* and *Rapanea melanophloeos* were the most abundant woody species within the forest reserve. *Hagenia abyssinica* and *Hypericum keniense* were also represented. The national park comprised mainly grasses in this vegetation zone.

Table 2. Key woody species of the forest reserve and national park in different vegetation zones of Mt Elgon Forest Ecosystem

Vegetation zone	Forest area	Key woody species (listed from most abundant to least abundant)
Mixed montane forest	Forest reserve	*Neoboutonia macrocalyx, Casearia battiscombei, Ekebergia capensis, Aningeria adolfi-friedericii, Celtis africana*
	National Park	*Ficus thonningii*, *Podocarpus falcatus*, *Croton microstachyus*, *Olea europea* subsp *caudata*, *Trichocladus ellipticus*
Bamboo vegetation	Forest reserve	*Podocarpus latifolius, Bersama abyssinica, Neoboutonia macrocalyx*
	National Park	*Podocarpus falcatus*, *Dovyalis abyssinica*, *Teclea nobilis*, *Diospyros abyssinica*
Sub-alpine heath	Forest reserve	*Juniperus procera, Erica arborea, Rapanea melanophloeos, Hagenia abyssinica, Hypericum keniense*
	National Park	-

Herbaceous species associations within vegetation zones

The mixed montane forest had 59 herbaceous species, of which *Pennisetum clandestinum, Cyperus articulates* and *Setaria plicatilis* were the dominant grasses, while *Hypoestes forskhalii* and *Galinsoga parviflora* were the dominant herbs within the forest reserve (Table 3). In the national park, *Cyperus difformis* and *Oplismenus hirtellus* were the dominant grasses, while *Hypoestes forskhalii* and *Achyranthus aspera* were the most abundant herbs. The bamboo zone had 36 herbaceous species, of which *Yushania alpina* and *Pennisetum clandestinum* were the dominant grasses, while *Hypoestes forskhalii* and *Cyathula polycephala* were the dominant herbs within the forest reserve (Table 3). *Yushania alpina* was the dominant grass, while *Hypoestes forskhalii* and *Achyranthus aspera* were the dominant herbs in the national park. The sub-alpine montane heath had 42 herbaceous species, of which *Cyperus difformis, Cyperus kyllinga, Cyperus articulates* and *Digitaria scalarum* were the abundant grasses, while *Alchemilla rothii, Oxalis comiculata* and *Satureja biflora*were the most abundant herbs within the forest reserve (Table 3). *Cyperus articulates, Cyperus kyllinga* and *Digitaria scalarum* were the dominant grasses, while *Commelina benghalensis* and *Tephrosiauniflora* were the dominant herbs within the national park.

Table 3. Key herbaceous species of the forest reserve and national park in different vegetation zones of Mt Elgon Forest Ecosystem

Vegetation zone	Forest area	Life-form	Key herbaceous species (listed from most abundant to least abundant)
Mixed montane forest	Forest reserve	Grass	*Pennisetumclandestinum, Cyperus articulates, Setariaplicatilis*
	Forest reserve	Herb	*Hypoestesforskhalii, Galinsoga parviflora*
	National Park	Grass	*Cyperusdifformis, Oplismenushirtellus*
	National Park	Herb	*Hypoestesforskhalii, Achyranthusaspera*
Bamboo vegetation	Forest reserve	Grass	*Ushania alpina, Pennisetumclandestinum*
	Forest reserve	Herb	*Hypoestesforskhalii, Cyathulapolycephala*
	National Park	Grass	*Ushania alpina,*
	National Park	Herb	*Hypoestesforskhalii, Achyranthusaspera*
Sub-alpine heath	Forest reserve	Grass	*Cyperusdifformis, Cyperuskyllinga, Cyperus articulates, Digitariascalarum*
	Forest reserve	Herb	*Alchemilla rothii, Oxalis comiculata, Satureja biflora*
	National Park	Grass	*Cyperus articulates, Cyperuskyllinga, Digitariascalarum*
	National Park	Herb	*Commelinabenghalensis, Tephrosiauniflora*

Stand structure

Stem density

The national park had a relatively higher stem density than the forest reserve within the mixed montane forest (Figure 2). In the bamboo zone, the forest reserve had a higher stem density than the national park. In the sub-alpine montane heath, the forest reserve had a higher stem density than the national park, whose physiognomy was largely grassland in this vegetation zone.

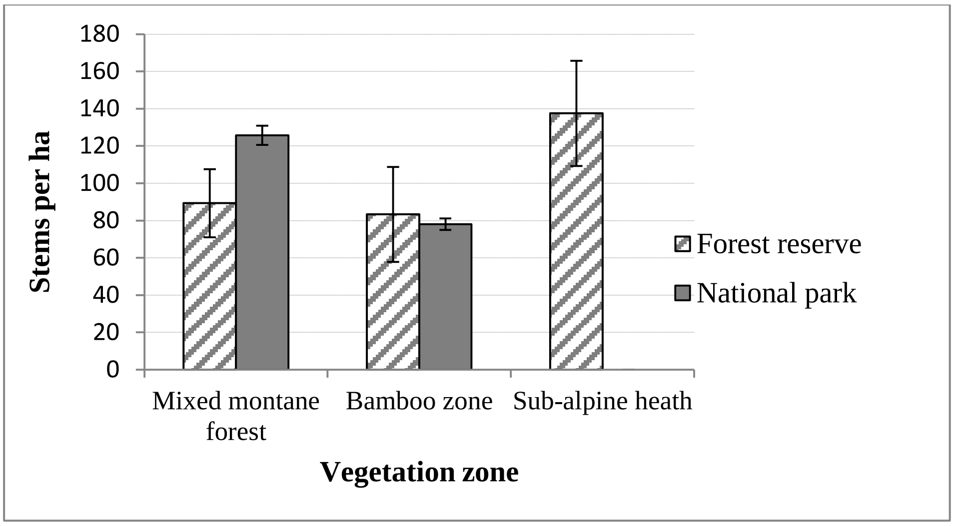

Figure 2. Stem density of the forest reserve and national park in different vegetation zones of Mount Elgon Forest Ecosystem

Stem diameter at breast height

Within the mixed montane forest zone, trees in the forest reserve had relatively larger diameter at breast height than those of the national park (Figure 3). However, in the bamboo zone, trees in the national park had larger stem diameter than those in the forest reserve. The national park had no trees in the sub-alpine montane heath.

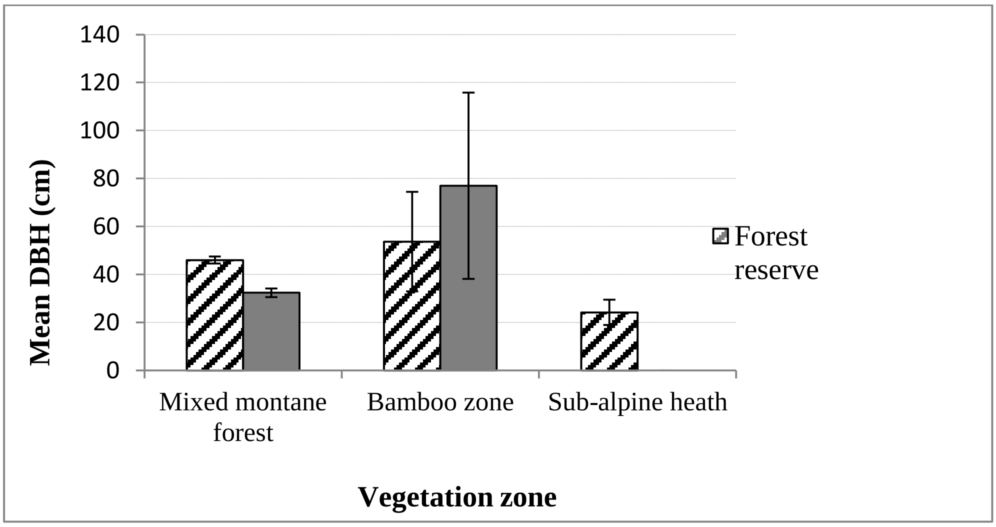

Figure 3. Mean stem diameter at breast heightof trees of the forest reserve and national park in different vegetation zones of Mount Elgon Forest Ecosystem

Forest canopy height

Among trees found in the mixed montane forest zone, those in the forest reserve were significantly taller than those in the national park (Figure 4). In the bamboo zone, however, trees in the national park were relatively taller than those in the forest reserve.

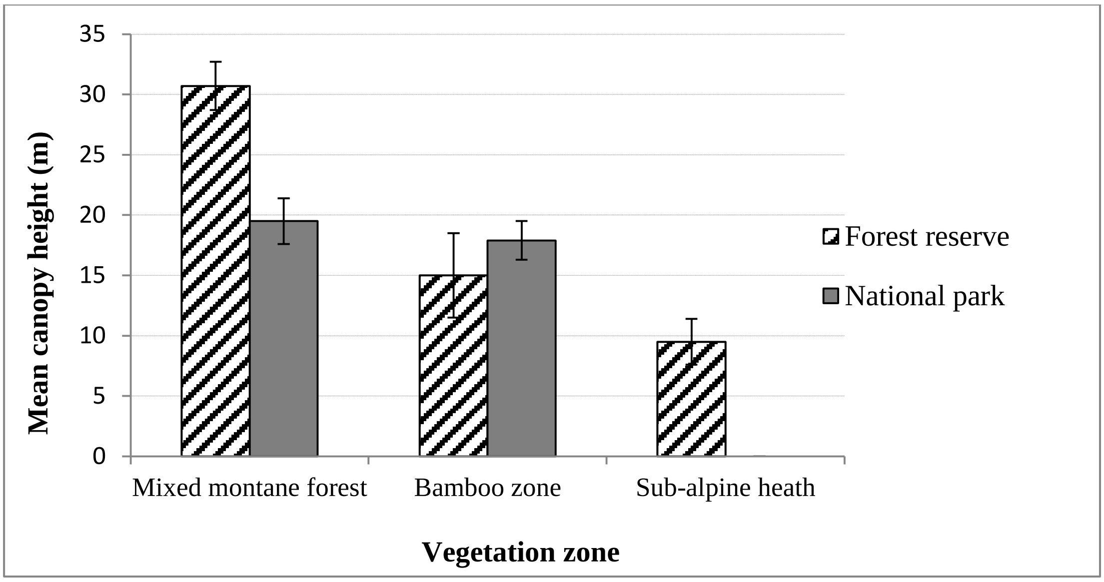

Figure 4: Mean canopy height of the forest reserve and national park in different vegetation zones of Mount Elgon Forest Ecosystem

Basal area

In the mixed montane forest zone, trees in the forest reserve had a relatively higher basal area than those in the national park (Figure 5). In the bamboo zone, trees in the national park had a relatively larger basal area compared to those in the forest reserve.

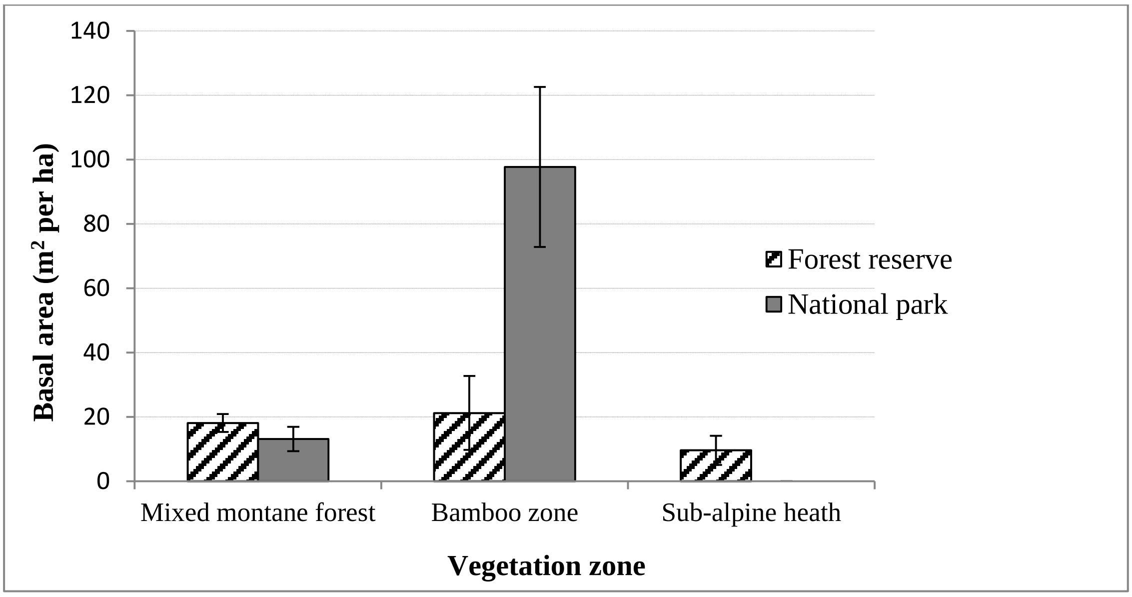

Figure 5: Basal area of the forest reserve and national park in different vegetation zones of Mount Elgon Forest Ecosystem

Discussion

Forest conservation status and species diversity

The Shannon diversity indices of this forest ecosystem have brought out an interesting scenario regarding the relationship between forest conservation status and species diversity.

The national park, which is presumed not to have experienced any anthropogenic disturbance since its gazettement in 1968, had a much lower species diversity than the forest reserve, which is exposed to continuous disturbance through resource exploitation. This observation can be explained by intermediate disturbance hypothesis (Wilson, 1994), which states that lack of site disturbance leads to lower species diversity because plant species that are favoured by the prevailing environment condition tend to dominate and outcompete the less favoured ones. The same hypothesis states that very high levels of disturbance lead to the elimination of less favoured species hence lowering species diversity. Thus, according to this hypothesis, less favoured species are vulnerable to competitive exclusion either due to lack of site disturbance or very high levels of disturbance. Moderate levels of disturbance, on the other hand, lead to a situation where both environmentally dominant species and rare taxa get a chance to establish. It is possible, therefore, that controlled resource use that prevailed in the forest reserve led to moderate levels of disturbance, while the exclusive resource preservation approach of the national park subjected it to a complete lack of disturbance or very high levels of it. It is not clear at this stage what may have caused a high level of disturbance in the national park.

Similarly, the forest reserve had the same woody species richness as the national park in the mixed montane forest, but the latter had a lower woody species richness in the bamboo zone than the former. In the sub-alpine montane heath, the national park had degenerated to a grassland, unlike the forest reserve that had at least seven woody species in this vegetation zone. The decline in woody species richness in the national park within the bamboo zone and sub-alpine heath is not consistent with the objective of the resource preservation approach, which is expected to contribute to the conservation of biodiversity and not loss of it. The forest reserve, which supported community-based conservation approach, appeared to perform better in biodiversity conservation in this regard than the national park. Two likely causes of low species richness in the national park are uprooting of woody plants by elephants and/or having a high number of herbivores than the carrying capacity of the protected area.

Changes in woody species associations

This study has recorded significant changes in woody species associations in the mixed montane forest of the ecosystem. Earlier studies (Tweedie, 1975; Howard, 1991) showed that *Olea hochstetteri* and *Aningeria adolfi-friedericii* were the most abundant species in both the forest reserve and the national park in this vegetation zone. However, the most abundant woody species in the forest reserve within this vegetation zone at the time of this study were *Neoboutonia macrocalyx, Casearia battiscombei* and *Ekebergia capensis,* which are early successional species. In the national park, the most abundant woody species were *Ficus thonningii, Podocarpus falcatus* and *Croton microstachyus,* some of which are also early successional species. The change in species associations in the forest reserve can be explained by the fact that logging operations occurred in the 1990s, during which most of the trees were clear-felled. The change in species associations in the national park and the emergence of early successional species also point to loss of tree species that were abundant between 1970s and 1990s. Since the exclusive conservation approach does not support logging, it is not clear how the tree species were lost in the national park. In case the tree species were lost as a result of uprooting by elephants, whose population is high in this national park, one would expect to see more losses in the bamboo zone because most of the elephants reside in this part of the forest ecosystem.

There were no changes in woody species associations in the bamboo zone in both the forest reserve and the national park. Earlier studies showed that the most abundant species of this vegetation zone were *Podocarpus spp* and *Yushania alpine* (Tweedie, 1975), which was also the case from our assessment. This was expected for the forest reserve because the terrain and bamboo cover within the bamboo zone generally makes logging operations arduous and costly. For the national park, the results present an interesting scenario because this was the vegetation zone where most destruction of trees would have occurred if tree loss in the national park was to be attributed to destruction by elephants. The results suggest that the change in woody species associations in the national park within the mixed montane forest, which we noted earlier, may have been caused by logging. In the sub-alpine montane heath, species associations of the forest reserve were largely unchanged. *Juniperus procera* and *Erica arborea,* which were recorded as the most abundant by earlier studies (Tweedie, 1975; Bakamwesiga *et al*., 2005) were still the most abundant woody species. In the national park, however, the population of *Juniperus procera, Cassipourea malosana* and *Sambucus adnate,* which were reported in earlier studies (Tweedie, 1975) had become negligible transforming the physiognomy of this section of the national park to a grassland.

Understanding the cause of forest degradation in the national park

The stand characteristics of the two forest management regimes can assist us to obtain insight on the source of forest degradation in the national park. The national park had a higher stem density (125.7 ± 5.2 stems ha^{-1}) than the forest reserve (89.3 ± 18.3 stems ha^{-1}) in the mixed montane forest. However, the mean DBH of its stems was much smaller (32.4 ± 1.8 cm) than that of tree stems in the forest reserve (46.0 ± 1.48 cm). This suggests that trees of the national park were younger than those of the forest reserve. This suggestion is confirmed by results of forest canopy height, which indicated that the forest reserve had a higher mean canopy height (30.7 ± 2.0 m) than the national park (19.5 ± 1.9 m) within the mixed montane forest. Since most trees in the forest reserve were clear-felled in the 1990s and were also subjected to continuous disturbance through controlled resource use, those of the national park could only be younger if the park was exposed to logging at some stage. One could argue that a high population of herbivores may also have affected tree growth leading to lower woody species richness. It is unlikely, however, that the herbivores would have reduced the DBH and height of existing trees.

In the bamboo zone, however, the stem density of the forest reserve (83.3 ± 25.5 stems ha^{-1}) and national park (78.1 ± 3.1 stems ha^{-1}) were almost similar. Trees in the national park had a much higher mean DBH (77.0 ± 38.8 cm) in this vegetation zone than those in the forest reserve (53.7±20.7 cm). They were also slightly taller (17.9 ± 1.6 m) than those of the forest reserve (15.0 ± 3.5 m). This suggests that logging operations that possibly occurred in the national park within the mixed montane forest did not extend to its bamboo zone. There was a negligible number of trees in the national park within the sub-alpine zone, unlike the forest reserve that had 9.6 ± 4.5 stems ha^{-1}. Since earlier studies indicated that the national park had cedar (*Juniperus procera),* pillarwood (*Cassipourea malosana)* and elder trees (*Sambucus adnate)* (Tweedie, 1975) in the sub-alpine zone, logging may have occurred also in this vegetation zone, significantly reducing the population of these tree species.

Overall, the stem density of the mixed montane forest of this forest ecosystem was relatively lower than that of many moist tropical forests. The stem densities of the bamboo zone and the sub-alpine montane heath were, however, within the expected range given that tree growth in the two vegetation zones tends to be affected by low temperatures and permafrost in the upper zone of the sub-alpine heath. Whereas it is predictable that the low stem density of the forest reserve within the mixed montane forest was perhaps caused by high intensity of logging over the past three decades, it is hard to understand the possible cause of logging within the national park, which is an area protected through exclusive resource conservation. Based on the plant species diversity and structural characteristics of this forest ecosystem, our results demonstrate that the forest reserve was better managed than the national park. However, it is clear that the forest reserve could be better managed than is presently the case, by setting allowable resource off-take targets for different management zones. The same cannot be said of the national park where logging went outside its legal mandate of exclusive resource conservation. Based on these results, it is extremely hard to support suggestions to revert forest management to exclusive resource conservation. Such an arrangement can only apply to selected portions of a forest reserve that are intended for exclusive conservation for given periods of time in order to promote regrowth or healing after disturbance or for preservation as heritage sites.

Conclusion

The results of this study have demonstrated that the floristic and structural integrity of Mount Elgon Forest Ecosystem is better in areas within the forest reserve than within the national park. The results make it plausible to suggest that controlled resource use under community-based conservation is a better resource management approach than exclusive resource conservation under the preservation approach. The community-based conservation approach should, however, be strengthened in order to achieve its objective of sustainable forest ecosystem management by defining permissible resource off-take thresholds beyond which resource exploitation would compromise ecosystem integrity.

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Piloting Mangrove REDD+ Project in Kenya

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Abstract
With the registration of Mikoko Pamoja project in 2013, Kenya became the first country in the world to successfully trade in mangrove carbon under the voluntary carbon market scheme. Mikoko Pamoja is verified under the Plan Vivo system and standards to trade ca. 3000tCO_2-eq/year for a crediting period of 20 years. Project activities range from avoided deforestation, mangrove reforestation, carbon monitoring and reporting, and sell of carbon credits. Protecting mangroves through Mikoko Pamoja not only mitigate impacts of climate change, but more importantly enhance income for communities whose livelihood is tied around mangrove ecosystem. Success of Mikoko Pamoja provides an opportunity for incorporation of mangroves and associated blue carbon ecosystems into National Determined Contributions to Paris Agreement.

Keywords: REDD+, voluntary carbon market, Paris Agreement, mangroves, Kenya

Introduction

Mangrove forests in Kenya provide a range of ecosystem goods and services. These ‘blue carbon ecosystems’ are important nurseries and breeding grounds for many varieties of fish and other wildlife (Kimani *et al*., 1996; Huxham *et al*., 2004; Mirera and Moksnes, 2015). They also play a key role in combating effects of rising sea levels, coastal erosion, and flooding from storm surges and tsunamis (Huxham *et al*., 2015). As an important source of renewable resources – notably fisheries and wood products – mangroves are important in coastal development (Kairo et al., 2001).

There are 60,323 ha of mangrove forests distributed all along the 536 km Kenyan coastline (Figure 1). These forests represent approximately 3 % of the natural forest cover or less than 1 % of the national land area. A large part of mangroves in Kenya (about 62 %) occur in Lamu County, followed by Kwale, Kilifi, Tana River, and Mombasa counties (Table 1).

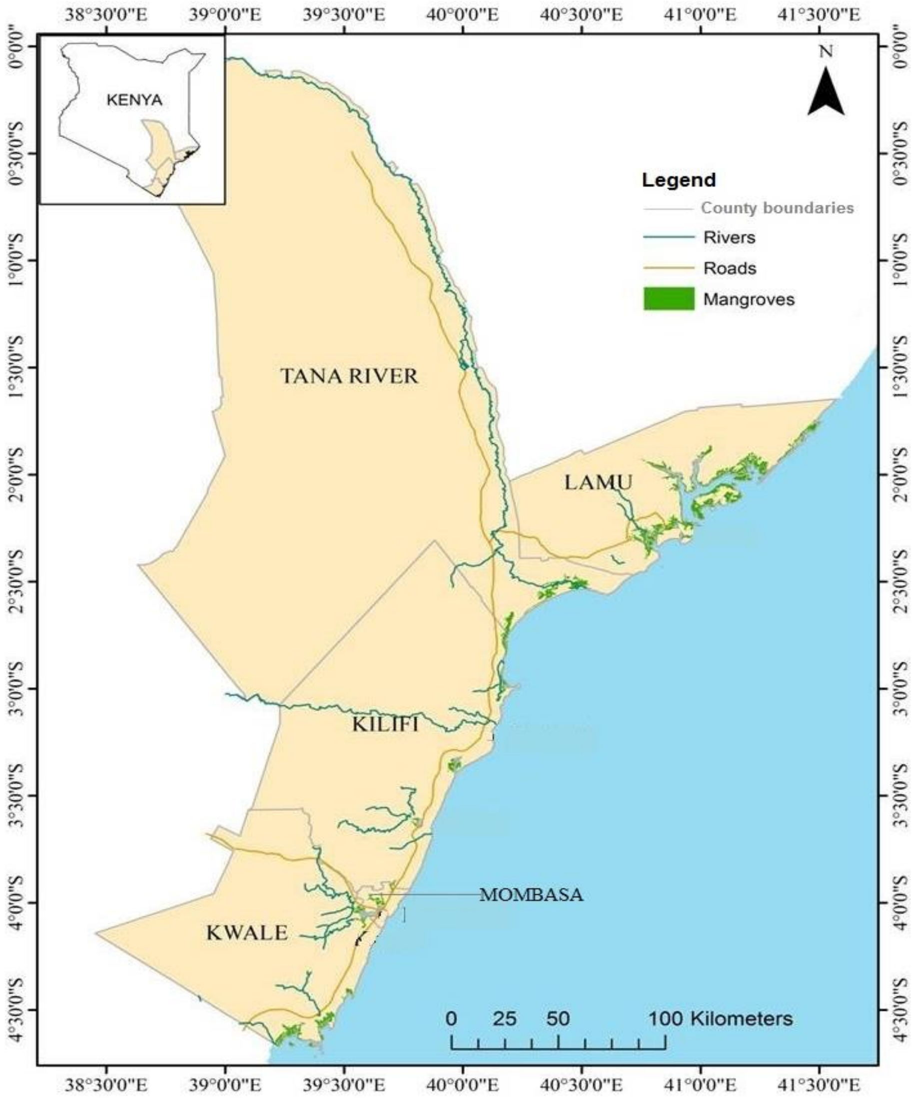

Figure 1. Mangrove distribution within the five counties along the coastal strip in Kenya

Table 1. Main mangrove areas per county along the Kenya coast (Source, GoK, 2017)

County	Forested mangrove area (ha)	%	Major mangrove areas in the county
Lamu	37,350	62	Northern Swamps, North- central, Southern Swamps, Mongoni & Dodori Creek, Pate Island
Tana River	2,314	4	Kipini and Mto Tana
Kilifi	8,535	14	Ngomeni, Mida, Kilifi and Mtwapa
Mombasa	3769	6	Tudo and Port Ritz creeks
Kwale	8,354	14	Gazi, Funzi, Vanga
Total	60,322	100	

There are nine mangrove species in Kenya (Table 2). Two of the species, *Rhizophora mucronata* and C*eriops tagal* are the most dominant and are represented in almost all mangrove formations. The rare species are *Heritiera littoralis* and *Xylocarpus moluccensis.* Major use of mangrove wood products include firewood, building poles, fencing and furniture.

Table 2. Mangrove species found in Kenya and their uses

Species	Local name	Main use
Rhizophora mucronata	Mkoko	Poles, dye, firewood, fencing, charcoal
Bruguiera gymnorhiza	Muia	Poles, firewood, charcoal
Ceriops tagal	Mkandaa	Poles, firewood, charcoal
Sonneratia alba	Mlilana	Boat ribs, poles, firewood
Avicennia marina	Mchu	Firewood, poles
Lumnitzera racemosa	Kikandaa	Fencing poles, firewood
Xylocarpus granatum	Mkomafi	Furniture, poles, firewood
Xylocarpus moluccensis	Mkomafi dume	Fencing poles, firewood
Heritiera littoralis	Msikundazi	Timber, poles, boat mast

Naturally growing mangroves exhibits horizontal distribution of species (or zonation). This is greatly influenced by levels of inundation, geomorphology, and the salinity (Tomlinson, 1986). A typical zonation of mangrove in Kenya starts with *Sonneratia alba* on the seaward margin, followed by large *Avicennia* and *Rhizophora mucronata*. In the creeks, *Rhizophora-Avicennia* mix is the most dominant. *Avicennia* expresses a double zonation but mostly found in the landward side Knowledge of mangrove distribution across the intertidal area is important in their management.

The diversity of fauna within mangroves is high due to ample food resources and a wide range of microhabitats in the system, such as; soil surface, permanent and temporary tidal pools, tree roots, trunks, and canopies (Bosire *et al.*, 2016). In Kenya these animals are represented by different phyla, ranging from protozoa and nematodes to molluscs, insects, crustaceans, birds, fish and mammals. The main groups are molluscs, crustaceans, fish and birds. Common groups of birds occurring in mangrove areas are: wading birds (herons, egrets, ibises), shore birds (plovers, sandpipers), floating, and diving birds (pelicans, cormorants, terns, gulls, kingfishers), birds of prey (fish eagle, osprey) and arboreal birds (bee-eaters, sunbirds). Further, mangrove forests receive thousands of migratory birds during winters every year (Huxham, 2010).

The principal groups of fish and crustacean associated with mangroves of Kenya are snappers, groupers, rabbit fish, grant, milkfish, mullet, terapons, carangids, shrimp, crabs, and oysters (Kimani *et al* ., 1996). The high biomass of fish, molluscs and crabs that mangroves support has significant economic value to artisanal and commercial fisheries.

Threats to mangroves in Kenya

In Kenya, mangroves are being lost and degraded due to a combination of human and natural factors, ranging from over-harvesting of wood products to conversion of mangrove land to other land uses, particularly for; agriculture, pond aquaculture, and infrastructure development (Abuodha and Kairo, 2001; Kirui *et al.*, 2012). In peri-urban areas, such as Mombasa, mangroves are being cleared to pave ways for infrastructure and human settlement (Bosire *et al*., 2014). Less than half of the original mangrove forests in Kenya remain, and the current rate of loss (about 0.7 % per year) is a major cause of concern (Kirui *et al*., 2012).

Climate change effects such as sea-level rise, increased rainfall, and storm surges are expected to negatively impact the remaining mangrove areas in Kenya (Kairo and Bosire, 2016). Site based responses to climate change effects such as the construction of hard civil structures are likely to exacerbate these effects. Of the predicted impacts to occur due to climate change, sea-level rise is perhaps the greatest threat to the ecological integrity of mangroves and associated biological resources (Gilman *et al*., 2008). In addition to shortages of harvestable wood products, declines in fisheries and increased shoreline erosion, destruction of mangrove forests in Kenya release huge quantities of stored carbon into the atmosphere, contributing to global warming and other climate change trends(Lang'at *et al.*, 2014). Fortunately, compensation for conservation and restoration can potentially help reverse these trends.

Marketing mangrove services in Kenya

Currently, the value of mangrove ecosystems is captured mostly for provisioning services, such as wood products, capture fisheries, and some value added cultural services such as ecotourism (Kairo *et al*., 2009). There is still a big gap in approaches for capturing the value of much of the regulating, supporting, and cultural services provided by mangroves. Payments for ecosystem service (PES) are emerging resource management tools that provide incentives for behavioral changes to increase the provision of ecosystem services, e.g. by discouraging loss and degradation of forests (Locatelli *et al*., 2014).

The Government of Kenya is pursuing market-based approaches to environmental protection, with a strategic focus on Ecosystem Services (ES) including; biodiversity, carbon sequestration, food provision, recreation, and shoreline protection (GoK, 2017). Specifically, the country's conservation strategy is to 'identify the benefits of environmental services and to seek a system where beneficiaries of such services pay service providers'. PES schemes are attractive because they reward those that supply or provide ES. However, the potential of forestry based PES schemes is hugely untapped in Kenya. Through the UK's Ecosystem Service for Poverty Alleviation (ESPA) funded projects in Kenya (http://www.espa.ac.uk), experience has been gained in facilitating the development and implementation of small-scale mangrove PES projects, with carbon credits supporting community development and mangrove conservation at Gazi bay. This work led to the establishment of **'Mikoko Pamoja'**- the world's first community based mangrove project funded by carbon credits' (http://www.planvivo.org/project-network/mikoko-pamoja-kenya/) – Project timelines and achievements are illustrated in Figure 2.

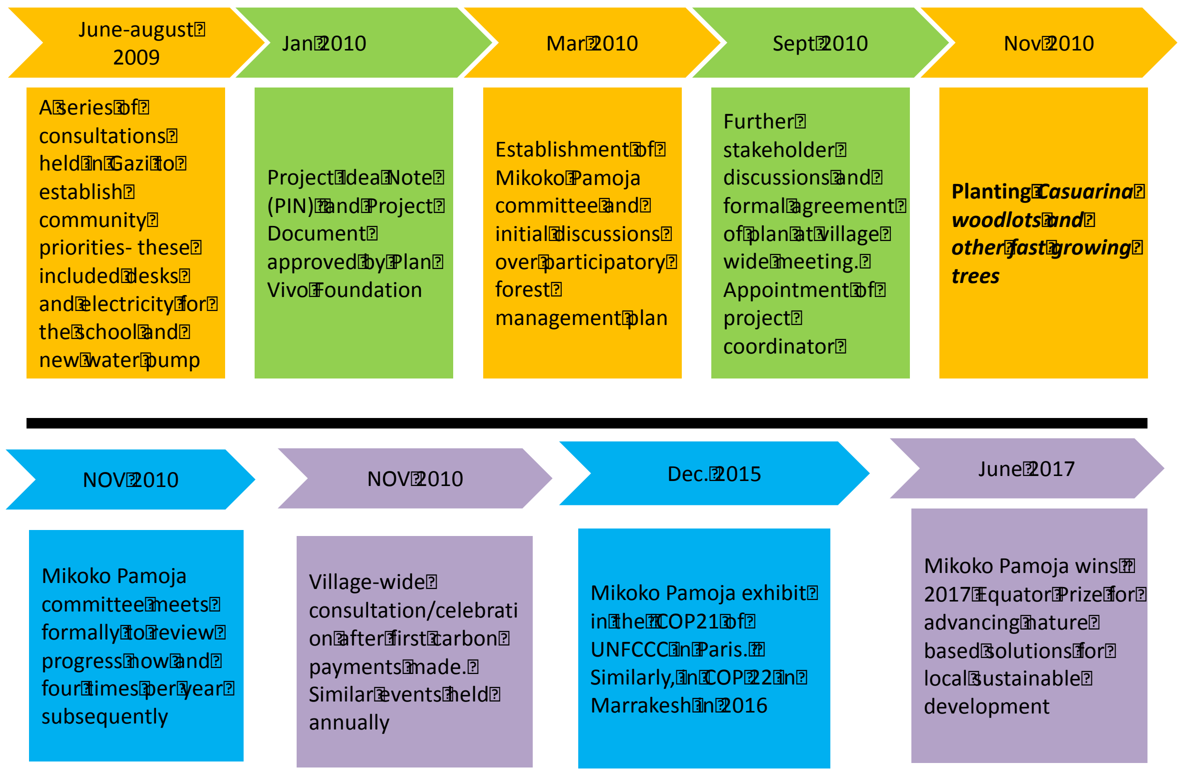

Figure 2. Mikoko Pamoja timeline and achievements

Mikoko Pamoja is being executed in the Gazi Bay area of the southern coast of Kenya, about 55 km south of Mombasa in Kwale County (Figure 3). The bay is bordered by 620 ha of mangrove forests, which are heavily used by local people as fishing ground and source of wood for building and fuel (Dahdouh-Guebas *et al.*, 2000). These forests have been extensively used and degraded – with large areas clear-felled in the 1970s and have not naturally recovered to-date. Selective logging of mangroves for commercial and subsistence use are still continuing in some stands and forest degradation continues through illegal harvesting of firewood and building poles. This has resulted in shortages of building poles and firewood, decreased fishery resources, and increased coastal erosion.

Social economic characteristics of Gazi Bay

There are approximately 6000 residents in the two villages, Gazi and Makongeni. The main ethnic group are the Swahili, and the Mijikenda of Bantu origin being the second commonest. Livelihoods are provided predominantly by fishing, farming and tourism. About 25 % of households receive remittances from kin outside of the area, and around one third of people are recent immigrants, who have come mostly to exploit the reef based fisheries. Other sources of employment are provided by titanium mining and sugar cane farming companies. Historically, local communities have exploited mangrove forests for firewood, construction poles and medicine. In Kenya, mangrove net benefits have been estimated to have a value of over US$ 2500 per hectare every year. Shoreline protection function of mangroves is allocated the highest value when compared to other habitat functions provided by mangroves (Table 3). It is therefore vital that they are protected for the benefit of the community and ecosystem functioning.

Table 3. Valuation of mangrove ecosystem in Kenya (Source: Kairo *et al.*, 2009)

Product and services	**KES ha^{-1}yr^{-1}**
Building poles	30,659.5
Fuel wood	4,505.0
Onsite fisheries	9,612.7
Beekeeping	1,249.5
Integrated aquaculture	408.0
Education & Research	65,469.6
Tourism	782.0
Carbon sequestration	21,896.0
Shoreline protection	134,866.1
Total	**269,448.3**

(1USD = KES103)

According to the Project Design Document (PDD) submitted to Plan Vivo (Huxham, 2010), the overall objective of 'Mikoko Pamoja' is to channel finance for the protection and restoration of mangrove ecosystems through the provision of and payment for quantifiable ecosystem services. Specific objectives are:

- To preserve the current quality and extent of the mangrove forests of Gazi Bay and of the services they provide to local communities
- To restore degraded areas of mangrove forest in Gazi Bay
- To raise income from forest resources, including carbon credits, for community benefit
- To establish alternative sources of timber and firewood in the Gazi area
- To work with the Kenya Forest Service and other government agencies to determine policy about engaging communities in land management, particularly through the provision of ecosystem services through international carbon offset markets

Eligible Mikoko Pamoja activities

Mikoko Pamoja activities are implemented through three distinct and interlinked project activities in Gazi bay (Figure 3 and Table 4).

▪ ***Activity 1***: *Avoided deforestation and forest restoration*. This involves protection of existing natural *Rhizophora mucronata* forest over an area of 100 ha. The area has previously suffered from deforestation and forest degradation.

▪ ***Activity 2***: *Reforestation and forest protection.* This has involved establishment of 10.0 ha of *Rhizophora mucronata* stand in formerly denuded area.

▪ ***Activity 3**: Reforestation and forest protection.* Replanting of a *Sonneratia alba* fringing forest of 40 - 70m depth and 800 m length, along a wave-exposed beach. Wood was originally removed from parts of the area for industrial use, leaving open areas of sand, which have not regenerated naturally, and exposing adjacent agricultural field to erosion. As part of community commitments in the project, replanting of about 4000 seedlings is undertaken in a succession of planting areas of about 0.4 ha every year. Cumulatively over the 20 years contracting period, the activity would have replanted a total of 8 ha of mangroves.

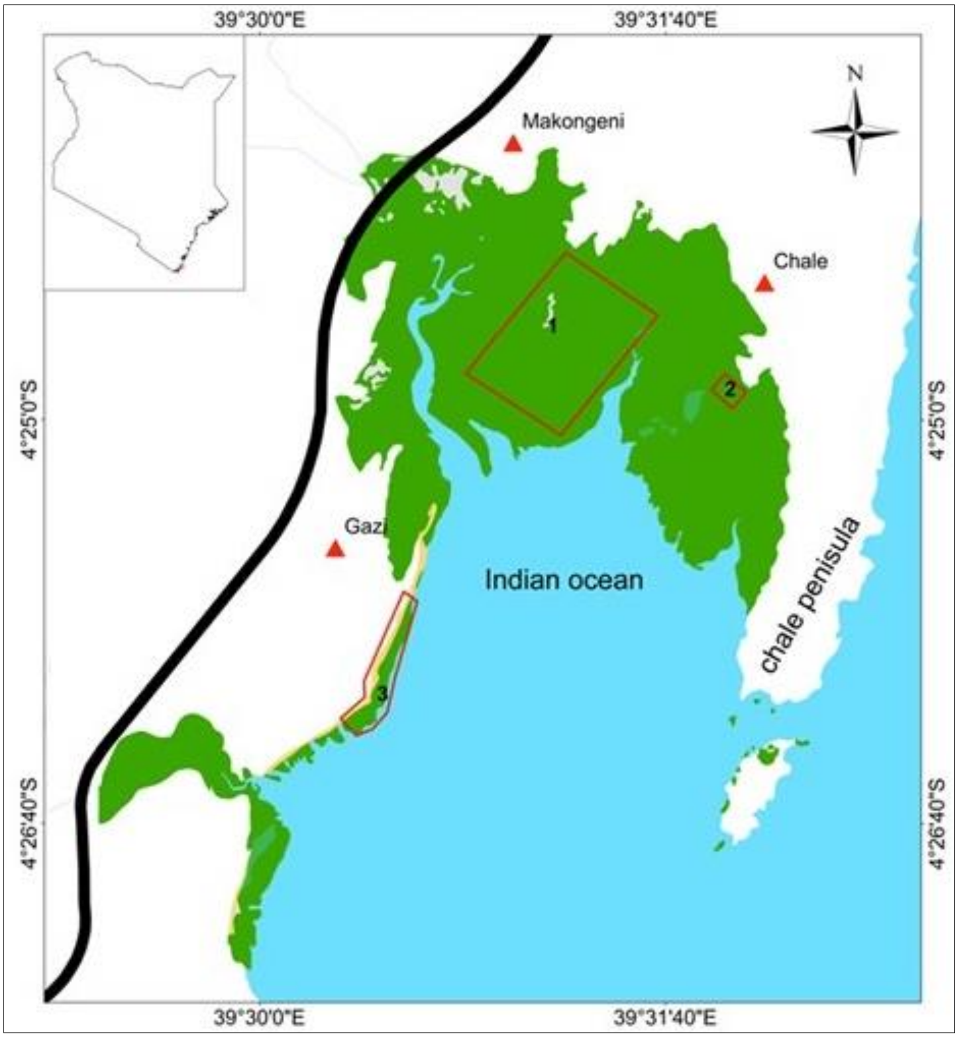

Figure 3. Map of Gazi showing Mikoko Pamoja activity areas

Table 4. The carbon benefits and projected income

Activity	Forest type	Area (ha)	Carbon benefit (t CO_2 ha^{-1} yr^{-1})	Total annual project carbon benefit from initial activities (t CO_2 yr^{-1})	Income ($)*
Avoided deforestation	Natural mixed	100	18 (based on mature forest, so conservative given this is a recovering forest)	1800	10,800
Reforestation	*Rhizophora* plantation	7	29 (based on 12 year old plantation)	203	1218
Reforestation	New plantation (*Sonneratia*)	5 (after 5 years)	4 (but increasing to ~ 10 after 10 years)	20	120
			Total	**2023 tCO_2**	**$12,138**

* assumes a conservative price of $6 $tonne^{-1}$ CO_2

Carbon Baseline

Mangrove forests develop and sustain above and below ground carbon pools. The latter constitutes a very long-term sink, with large amounts of carbon held in peat (Gress *et al.*, 2016). Gazi Bay is among the best-studied mangrove system in the world (Kairo, 2001) ; and there is detailed information on above and below-ground carbon for different forest types (Tamooh *et al.*, 2008; Cohen *et al.*, 2013). The above ground biomass of mangroves in Gazi is estimated at 250 t/ha, although this varies depending on age, species, and location in the intertidal area. Below-ground biomass (to 60cm depth) varies from 7.5 – 75 t/ha. This equates to approximately 155,000 t aboveground and 23,250 t belowground (178,250 t total) in the Gazi area. In addition, mangroves sequester around 1.5 t C/ha/yr in accretion of new sediment, and approximately 5 t C/ha/yr in new biomass (for a mature forest – rates are higher for young forests and plantations).

Ownership of carbon rights

All mangroves in Kenya are gazetted as government reserve forests. Management of these forests is vested with the Kenya Forest Serve (KFS), either alone, or in partnership with Kenya Wildlife Service (KWS) whenever they occur in marine protected areas (MPA). Under the provisions of Forest Conservation and Management Act (2016) Community Forest Associations (CFAs) are encouraged to develop management plans for local forests and to benefit from the goods and services they supply. Mikoko Pamoja is managed through a local CFA that has been involved in the development of participatory forest management plan for Gazi and in the signing of Forest Management Agreement (FMA) with KFS. The management agreement enables Mikoko Pamoja to engage in sale of carbon credits from the designated mangrove area. Mikoko Pamoja is verified under the Plan Vivo System and Standards, a framework for supporting communities to manage their natural resources more sustainably with a view to generating climate, community, and biodiversity benefits through payments for environmental services; in this case carbon. Income from carbon credits, worth over US$ 12,000 each year, is used to fund continued mangrove conservation activities as well as priority projects chosen by communities, such as; water and sanitation, health and education (Abdalla *et al*., 2015). Communication of the value of blue carbon in both economic terms, and in terms of ecosystem services provided by mangrove habitats was key to community uptake of Mikoko Pamoja. The building blocks of Mikoko Pamoja, which could be replicated to other mangrove areas, have been identified as good science, community buy-in, and government support (Abdalla *et al*., 2015).

Benefit of Mikoko Pamoja

Mikoko Pamoja has improved the education, water and sanitation systems as well as the management of mangrove ecosystem in Gazi Bay (Table 5). The purchased books and stationery for local schools have helped improve the education system in the area. Currently, the projects is meeting the demand of 70% of the population by supplying water through water points or connecting water pipes directly into people's houses. Mikoko Pamoja supports nature based enterprises such as mangrove ecotourism and integrated aquaculture. These activities are contributing to improved livelihood for the local people living in this community.

Table 5. Impacts of Mikoko pamoja

Activity	Input	Output	Outcome	Impact
Installation of water	Purchase of 2 water storage tanks,2 water pumps, piping and creation of three water points	2 water sellers employed -Generation of revenue from the sale of water - Piping water to the community health center -installing water to Makongeni primary(ongoing)	Sustainable safe water to about 70% of the community -Reduction in number of water borne diseases by 47%-2015 - free water for 3 schools ~1000 students and local dispensary -Better learning environment	Improved Livelihood as a result of reduction of the price of water from Ksh 20-Ksh 3 per 20L jerican -Reduced number manhours lost in drawing water
Purchase of books and Renovating classrooms	-Provision of 287 text books-Gazi Primary school and 315 textbooks-Makongeni Primary school -Roofing sheets, cyprus wood,3 iron doors	-2 classes renovated -Increase in number of books in a class	-Reduction in the ratio of students sharing a textbook -Better learning environment	Improved performance of students in school Improved living standards as a result of improved education
Environment education	Education on importance of mangroves in schools	~1500 students from 15 schools educated on mangroves in 2016.	-Participation in more environment competitions and events from 1	Increase in mangrove conservation

Activity	Input	Output	Outcome	Impact
	-Engagement of students in marking environmental events -mangrove competitions (local and international) e.g. by Mangrove action project	So far 718 students have visited in 2017 -360 students from Invicta grammar school in England educated on mangroves -2 international training 55 trained In 2016 -13 teachers trained in 2017	event in a year to 3 -Improved knowledge of the marine environment	
Link with external communities	3 interested community conservation group visited and educated on mangroves (Big Ship in Mikindani, Madagascar and Mwikamba in Diani)	300 mangroves planted with Mwimkamba	Increased knowledge on importance of mangroves	Increase in areas under mangrove conservation
woodlot	-2500 casuarina planted -Bsc student recruited to monitor the woodlots	-Data on the status of the forest gotten	Casuarinas currently providing building poles and firewood for the communities	Reduction in mangrove degradation
livelihood	employment	-4 directly employed: project Co-ordinator, Assistant co-ordinator and 2 community scouts -32 indirectly employed in 2016 through planting and monitoring activities	-Minimal cutting as a result of Increased surveillance in the project area	-Increased conservation of the mangroves -Improved livelihood

Conclusion

Unsustainable exploitation of mangrove forests in Kenya has led to shortages of firewood and building materials, decline in fisheries, and increased shoreline erosion. Mikoko Pamoja is reversing these trends by attracting carbon finances and channeling them to the conservation and restoration of degraded mangrove areas as well as initiating community development projects in Gazi bay. The project is supported by the village community, consisting largely of fishers whose livelihoods are connected to the health of the mangroves, with whom there is a clear payments arrangement for sold carbon credits. Part of the payments covers dedicated staff time for the project, with the remaining funds being allocated to community projects and additional mangrove activities overseen by village leaders.

Success of Mikoko Pamoja stems from strong community support for the project, well established and ongoing scientific research on the mangroves in the area, knowledgeable government agencies interested in partnering with the local community on the project, and a supportive national policy that promotes participatory forest management.

One of the strengths of the project is the approach taken to reduce illegal harvesting of mangroves and leakage by including the cultivation of fast-growing terrestrial forest plantations to serve as alterative wood sources. The project has also established mangrove ecotourism – an informational boardwalk managed by the Gazi women for recreation and school educational activities. Recently, the project partnered with World Wide Fund for Nature (WWF) to promote energy saving stoves and solar lights that would further reduce community dependency on mangrove forests for wood. Mikoko Pamoja provides a an excellent example of 'triple-win'' situation: Community, Climate, Biodiversity

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Distribution of Herpetofauna Across Vegetation Zones of Mt Elgon Forest Ecosystem

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Abstract

There are information gaps on the effect forest degradation on the distribution and abundance of reptiles and amphibians in Mt Elgon Forest Ecosystem. A study of reptiles and amphibians of the forest ecosystem was conducted with a view to determine their distribution and abundance across vegetation types. The vegetation types included mixed montane forest, bamboo zone and sub-alpine heath. The methods used included time-limited searches, pitfall trapping and opportunistic sampling. A total of 10 species including three amphibians and seven reptiles were recorded. Species richness declined from mixed montane forest to the bamboo and sub-alpine heath. Anthropogenic influence had a negative effect on species abundance. Degraded forest sites tended to have fewer populations of reptiles and amphibians than intact zones. The study suggests that degradation of herpetofaunal habitats poses a serious conservation challenge for reptiles and amphibians in this forest ecosystem.

Key words: Distribution, abundance, reptiles, amphibians, Mt Elgon forest

Introduction

The forests of East Africa are generally thought to consist of two non-overlapping herpetofauna. These include the twin assemblages of an eastern extension of the Congo-Guinean forest block stretching from Cameroon to western Kenya and the Eastern Arc Mountains and the East African coastal forests. Despite pressures such as human population increase leading to forest loss as demand for agricultural land increases, detailed studies of these globally biodiversity hotspots have only progressed slowly in the last few decades. However, this knowledge is increasingly becoming important as an integral part of Kenya's rich biodiversity. Anecdotal reports indicate that the remnant forests of East Africa are important refuges for reptiles and amphibians. The studies that have examined the herpetofauna of the Congolean block associated forests in East Africa include those by Loveridge (1935, 1942a, 1942b, 1957). These eastern relicts include the transboundary Mt Elgon ecosystem and Kakamega Forest in Kenya, besides Budongo, Bwamba, Kibale, Bwindi and Mabira in Uganda. Some of the recent attempts to address this gap the herpetofauna of Bwindi in southwestern Uganda and Kakamega Forest have been inventoried (Lötters *et al.*, 2007; Wagner *et al.*, 2008).

In this report the herpetofaunal diversity in four distinct eco-climatic zones is examined in Mt Elgon ecosystem. Mt Elgon is one of the five major water towers in Kenya and a listed Important Bird Area (IBA). Despite this no comprehensive herpetofaunal work has ever been done. It is against this background the present study was initiated as part of a broader biodiversity assessment. This study aimed to determine the distribution and influence of vegetation on herpetofauna assemblages. It was predicted that there is change in amphibian and reptile composition along the eco-climatic zones.

Methods

Sampling of amphibians and reptiles was carried out for a period of 12 days from 4th to 16th May 2017. A stratified approach based on four eco-climatic zones in Mt Elgon was used in selecting sampling locations namely: natural forest, bamboo, sub-alpine and alpine zones. In each zone, systematic searches were carried out along each transect by a team of two researchers walking at a speed of 1 km/hr. Time limited searches (TLS) as described by Karns (1986), Heyer *et al.* (1994) and Sutherland (1996) was used. All possible amphibian and reptile microhabitats such as wetlands, under leaves debris, on trees, decomposing tree stumps and logs were intensively searched for one man hour per sample. To supplement the search efforts, trapping with pitfalls along drift fences was employed: X-shaped drift fence/pitfall trap arrays (Corn, 1994) with segments of 5m length were used. The pitfall traps consisted of 5 l plastic buckets flush with the ground; with a total of five (5) buckets in every trap station. Traps were set for three days (trap nights). Checking was done once every morning not later than 0830 hrs. Night sampling was also carried out mainly targeted at amphibians and other nocturnal herpetofauna at suitable wetlands in Kaberwa area. This lasted approximately two hours between 18.00 to 20.00 hrs.

Additional data was obtained from opportunistic observations from areas outside prescribed sampling protocols. Species were identified according to Channing and Howell, 2006 (amphibians) and Spawls *et al.*, 2002 (reptiles). For each animal observed, we recorded the identity, counted the number of individuals and noted the habitat. Where necessary, voucher specimens were euthanized and deposited at the National Museums of Kenya.

Data was analyzed using EstimateS 9.1.0 statistical software. Using 100 randomized runs, species richness in each sampling block was calculated based on ICE (Incidence-based Coverage or presence-absence estimator).

Results

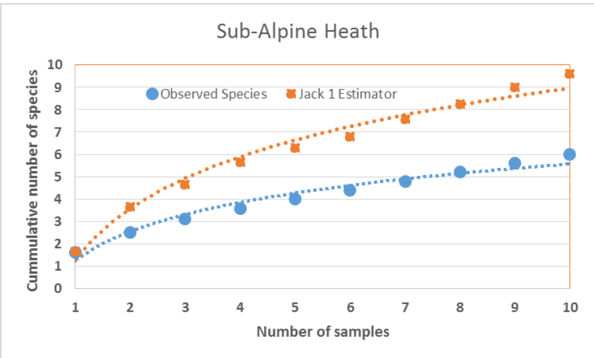
A total of 10 species including three amphibians and seven reptiles were observed in Mt Elgon in May 2017. See Table 1.

Table 1. Observed number of species in Mt Elgon in May 2017

Species	Eco-Climatic Zone				Species Abundance
	Forest	Bamboo	Subalpine	Alpine	
Phrynobatrachus graueri	27	0	0	0	**27**
Amietia nutti	12	5	0	0	**17**
Trioceros hoehnelii	6	0	0	0	**6**
Trioceros ellioti	1	0	0	0	**1**
Philithamnus battersbyi	1	0	0	0	**1**
Adolfus jacksoni	1	0	0	0	**1**
Trachylepis striata	0	12	1	0	**13**
Xenopus borealis	0	10	0	0	**10**
Trachylepis varia	0	0	8	11	**19**
Adolfus masavensis	0	0	0	1	**1**
Species Richness	**6**	**3**	**2**	**2**	**10**

The natural forest had the highest species richness (six species) followed by bamboo (three species). The lowest species richness was recorded in the sub-alpine and alpine zones with two species each. Grauer's puddle frogs were the most abundant within the natural forest. On the other hand, one of the rare species was the Alpine lizard with only a single individual documented in the meadow grassland. Other species which were only recorded in singletons were Montane side-striped chameleon, Jackson's forest lizard and Striped skink.

One of the general characteristics of ecological communities is that the number of species accumulates with increasing area sampled. In the present study, the sampling appeared rather incomplete across all the sampling blocks. None of the species curves reached asymptote as would be expected in a complete inventory (Figure 1A–D). .Some of the species documented from Mt Elgon are shown in Figure 2.



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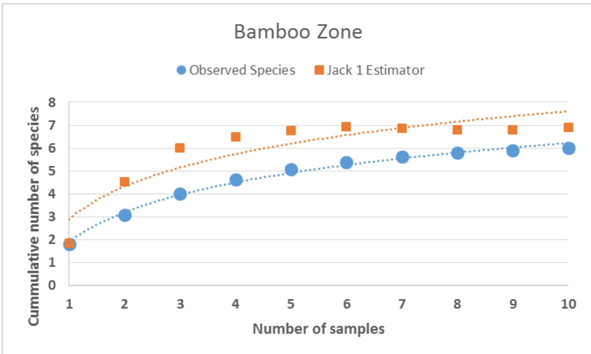

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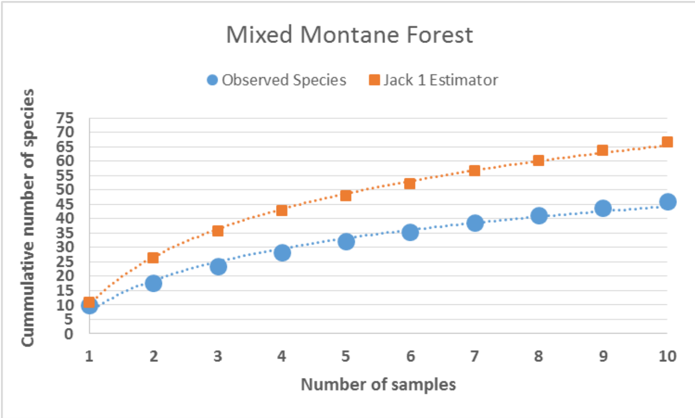

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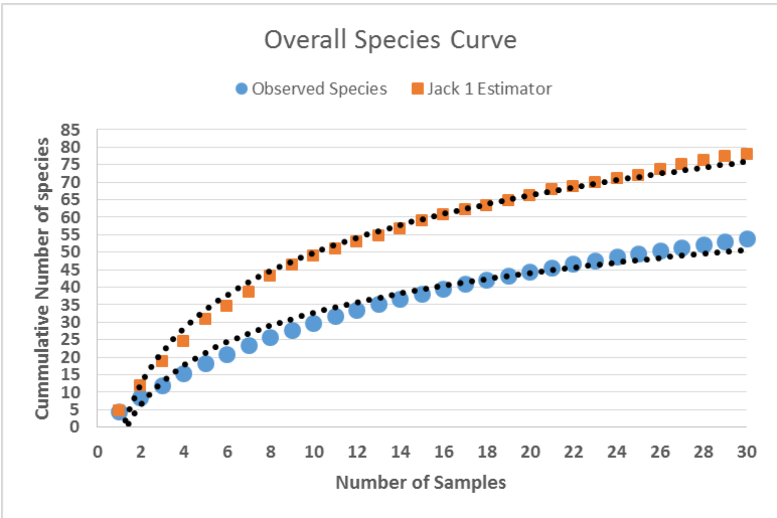

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Figure 1: Species accumulation curves for reptiles and amphibians for A) Sub-alpine Heath, B) Bamboo zone, C) Mixed montane forest and D) Pooled data for all the three eco-climatic zones in Mt Elgon

Discussion

Reptiles and amphibians are highly secretive, making their detection rate generally slow and unpredictable. It has also been documented that some species can go for long periods without food under aestivation (Spawls *et. al*., 2002). One of the key factors that influence detectability of herpetofauna is seasonal variation; for instance, amphibians are considered more abundant during the rainy season. Therefore, a complete species inventory for a given site is usually based on long-term studies. In Mt Elgon, the available literature indicates that there are about 58 species including 40 reptiles and 14 amphibians (e.g. National Museums of Kenya & Makerere University, 2004; Lötters *et al.*, 2006). This reveals that the data obtained in the current assessment is under-representative of the expected herpetofauna of Mt Elgon.

Species turnover along habitat and/or altitudinal gradients is a research area gaining momentum in Eastern Africa and elsewhere. A recent study in Taita Hills documented an inverse relationship between herpetofauna diversity and abundance and elevation Kenya (Malonza & Veith, 2011).A study of birds of the eastern Arc Mountains in Tanzania revealed a clear distinction between lowland and montane assemblages (Romdal & Rahbek, 2008). However, a study of the amphibian fauna of Monts Doudou in Gabon only revealed moderate evidence of altitudinal effects (Burger *et al*., 2004).In yet another study in Mt Kenya, a clear ecological separation of some species was supported even though no clear species richness pattern emerged (Malonza, 2015). In the present study, only six species were documented in the sub-alpine heath eco-climatic zone compared to 46 in the mixed montane forest. Some species, e.g. the Genus *Adolfus*, tend to show a distinct ecological separation from the mixed montane forest to the sub-alpine alpine zone. *Adolfus jacksonii* was documented within the mixed montane forest (2,372 m a.s.l.) while *Adolfus masavensis* was restricted to the sub-alpine zone (about 3,372 m a.s.l.). Even though the current data was not sufficient to determine any elevational correlation, species richness was higher in the natural forest (2,086 to 2,270 m a.s.l.) but decreased towards the sub-alpine and alpine eco-climatic zones (2,922 to 3,406 m a.s.l.). This is perhaps due to the general limitations of behavioural thermo-regulation mechanisms of herpetofauna species.

There are other factors that, either positively or negatively, influence the distribution and abundance of herpetofauna. Anthropogenic activities such as cattle grazing, charcoal burning, logging, cultivation, wild fires and land clearing for settlement are considered threats to the conservation and management of reptiles and amphibians. Most of these threats were documented in Kaberwa and Sosio forest blocks of Mt Elgon. Mt Elgon National Park (not adequately sampled in the current study) could perhaps offer the best comparative data to determine the effects of these activities. Illegal off-take of reptile and amphibian species for trade e.g. Central African Rock Python also pose serious conservation threats.

Based on literature, there are additional four species that were expected but not documented in the present study. These include Mt Elgon montane torrent frog (*Arthroleptides dutoiti*) Newmann's Terrapin (*Pelomedusa neumanni*) Lionate blind snake (*Afrotyphlops lineolatus*) and Gold's tree cobra (*Pseudohaje goldi*). In particular, the status of the stream dwelling Mt Elgon montane torrent frog which was last documented in 1960s has remained highly uncertain, despite targeted efforts from 2001 to 2017.It is not clear whether this is due to deterioration of the stream habitats, inaccessibility or poor timing.

 **Nutt's river frog**	 **Northern clawed frog**
 **Variable skink**	 **Von Hoehnell's chameleon**
 **Battersbyi's green snake**	 **White-lipped snake**

Figure 2. Some amphibians and reptiles of Mt. Elgon ecosyste

Conclusion and recommendations

There is indication that an ecological separation of the herpetofaunal assemblages along eco-climatic zones of Mt. Elgon exist. The ecosystem generally supports a high diversity of reptiles and amphibians. However, human encroachment is posing a major threat to key habitats like wetlands and forests which could result in local extinctions of some species.

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Effects of Climate Variability on Wild Edible Plant Products Used as a Coping Strategy by Pastoralists of Northern Kenya

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Abstract

Drought, a manifestation of climate variability has become a perennial problem in Kenya with chronic vulnerability being concentrated in Arid and Semi-Arid lands (ASALs). Traditionally, pastoralists have used wild edible plant products namely; fruits, vegetables and seeds as a coping strategy when faced by climate related calamities. However, recent studies have shown that pastoralists' traditional coping strategies have become weak as a result of recurrent droughts. The overall objective of this study was to investigate the effects of climate variability on wild edible plant products. This study applied; household interviews, focus group discussions and key informant interviews to collect data. Quantitative data derived from the household interviews were edited, coded and analyzed using the Statistical Package for Social Sciences (SPSS) version 20. Descriptive statistics were run to give frequencies and percentages. Results of this study indicate that wild plant fruits and vegetables were occasionally used as food by pastoralists during times of drought. These wild products were gathered by women and children. The findings also indicate that recurrent droughts have affected the availability of wild edible plants that pastoralists used to rely on, hence increasing the distance they travel to look for such products. This study revealed that some new plants have sprouted in the area that are not fit for human consumption. The study came up with two recommendations: to train livestock keepers on appropriate coping strategies which are sustainable, and to train pastoralists on the best methods of conserving the wild edible plants.

Keywords: Climate variability, coping strategies, pastoralists, wild edible plants

Background Information

Climate variability is one of the major challenges for dryland ecosystems which comprise more than 80 % of Kenya. IPCC (2014) gives indicators of climate variability as extended droughts, floods, and conditions that result from periodic El Niño and La Niña events. Droughts are not new phenomena in Kenya with their characteristics - intensity, duration and spatial extent – varying from one event to the other. The drought cycle in Kenya dates back to more than three decades ago. According to Huho and Mugalavai (2010) as many as 28 droughts have been recorded in the past 100 years, at an increasing frequency. Droughts are often nation-wide, but normally have the most severe effects in ASALs. The frequency of occurrence and severity of droughts have been increasing over time (Huho and Kosonei, 2013). These droughts have resulted in immense loss of resources and affected livelihoods of many who depend on the dryland ecosystem for survival, particularly the pastoralists. The enormous changes due to unreliable rainfall means forage is affected as the ground remains dry and nothing grows. Livestock productivity goes down and sometimes the livestock die in large numbers. As a result of this, the pastoralists have developed a set of indigenous strategies and mechanisms that enable them to deal with multiple threats, variability and environmental changes. These mechanisms have enabled them to survive and effectively use the harsh and highly variable environment. Some of these strategies are ecologically-based, while others depend upon socio-economic and cultural mechanisms (Eriksen, *et al*., 2008). One of these strategies is reliance on wild edible plant products namely; fruits, vegetables and seeds. Wild edible plants refer to species that are neither cultivated nor domesticated but are available in their wild natural habitat (Shumsky, *et al*., 2014). These wild edible plants (WEPs) are a common and effective coping strategy used to increase socio-ecological resilience in Sub-Saharan Africa where agricultural systems are often sensitive to environmental perturbations and instability. Pastoral communities occasionally use wild fruits and vegetables as food during times of natural calamities (Langil and Ndathi, 2001).

This coping strategy appeared to have worked well since time immemorial. But to what extent this strategy has been affected by severe and frequent droughts is not known. This study was therefore aimed at investigating the extent at which wild edible plants as a coping strategy was being affected by climate variability. In order to achieve this, the study sought to establish: the most common wild edible plants for the pastoralists in Northern Kenya; how climate variability has affected these wild edible plants; and if there are other plants that have grown to replace wild edible plants which are depleted.

Materials and Methods

Study sites

This study was undertaken in three villages in Isiolo County, namely; Kambi Odha, Kambi Bule and Kambi Garba. These areas are occupied by pastoralists and agro-pastoralists including Borana, Somali, Turkana, Samburu, Rendille and Ameru. This study focused only on the Borana community. This was because the Borana are the largest group in Isiolo County.

Methods

A total of 400 respondents were interviewed with the unit of study being the household heads. This study collected both qualitative and quantitative data. Systematic sampling techniques were applied to select respondents for the interviews, while purposive sampling was used to select focus group participants and key informants. Secondary data were collected from literature, while primary data were gathered using questionnaires, focus group discussions, key informants and by direct observation.

Qualitative data derived from direct observations, focus group discussions and key informant interviews were presented in discussions. Quantitative data derived from household interviews were edited, coded and entered into a computer. The Statistical Package for Social

Science (SPSS) software version 20 was used for the analysis. Descriptive statistics were run to give frequencies and percentages on multiple response questions.

Study findings

This study revealed that pastoralists of Northern Kenya have been relying on some wild edible plants during the drought period. The products are relied on during times of crisis as a mitigation measure against food shortages. On whether there were traditional fruits, vegetables and roots which used to be eaten by the pastoral communities of Isiolo County, 86 % of the respondents indicated that there were, while 14 % said there were none. Figure 1 below gives a summary of the outcome.

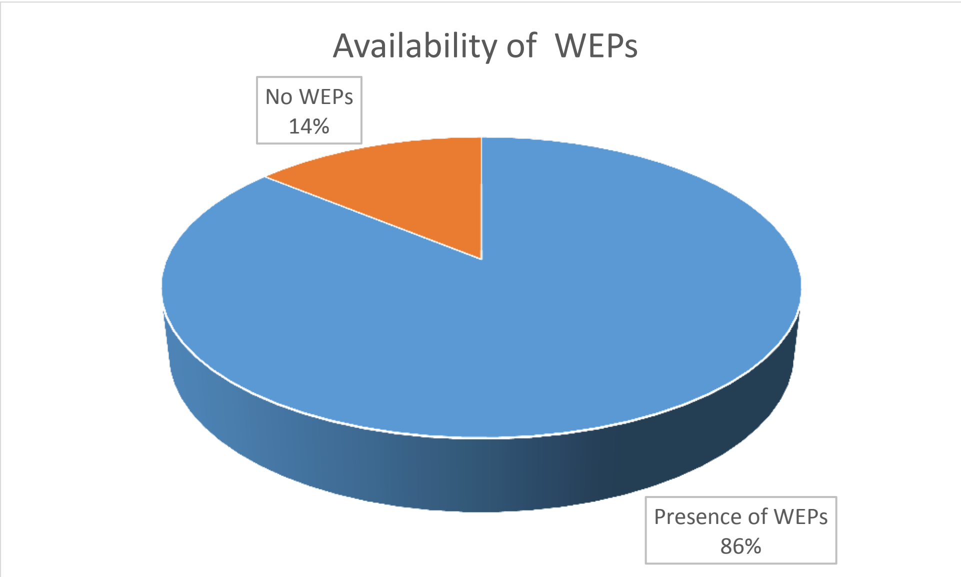

Figure 1. Response relating to availability of wild edible plants

Types of edible fruits, vegetables and seeds

Wild edible plants refer to species that are neither cultivated nor domesticated but are available in their wild natural habitat. Wild fruits, vegetables and roots are occasionally used as food during drought, with some being available during droughts period while others are collected before the onset of a drought. During droughts and famines, pastoralists collect wild foods such as roots, tubers, leaves and seeds on a regular basis. Collection is carried out by women and children. The products are relied on during times of crisis as a mitigation measure against food shortages. On whether there were traditional fruits, vegetables and roots which used to be eaten by the Borana pastoral communities of Isiolo County, 85.8 % of the respondents responded on the affirmative, while 14.3 % did not. Types of fruits given included; *deka* (*Grewia tembensis), mader (Cordia gharat*), *qurqura* (*Zizyphus mauritiana), jaj jab (Berchemia*), o*gomdi (Grewia villosa)* and *kumude (Lannea alata).* These plants produced fruits which were eaten by the Borana but mostly during periods of droughts and famines.

Others, such as *mader (Cordia gharat*) produced edible fruits and their gums were chewed during drought periods. Conversely *urbu (Acacia tortilis)* pods were boiled and eaten during droughts. Some of the plants, such as *iddi hiddi* (*Solanum scabrum*) also produced vegetables and fruits eaten during droughts. Other wild vegetables eaten as revealed during focus group discussions include *sumalele (Mormodica trifoliolata)* which is boiled in water, and mixed with salt to form porridge. The *ng'orondo (Cyphostemma nierrense)* plant also contributed to survival during drought. One of the elders made this statement, *"when herding, herders ate these plants and they got satisfied such that when they got home they did not eat anything more."* **(Elder, Kambi Odha, Isiolo).**

Time when the plants are available

According to the respondents, some of these fruits and vegetables are available during the drought periods but others have to be collected before a drought and preserved for latter use. This study revealed that there are also wild vegetables that consist of tubers such as; *sumalele* (*Mormodica trifoliolata*), *buri, hindy* and *ruma (Commiphora spp.*). Vegetables from these plants are boiled in water, and mixed with salt and milk to form a porridge. Leaves from the n*g'orodo* (*Cyphostemma nieriense*) plant also contribute to survival during times when domestic animals are not able to produce sufficient milk, which is the staple food for the pastoralists. The parts eaten differ from one plant to the other since some produce edible seeds, others gums, vegetables, or roots which are consumed.

Edible fruits, vegetables and seeds that are locally extinct

On whether wild plants have disappeared, a majority (88.5 %) of the respondents affirmed that many of the plants had disappeared while 11.5 % were of the opinion that they had not disappeared. It also came out clearly from the study that the distance travelled while going to collect wild fruits and vegetables had changed as a result of climate variability. A majority (81.3 %) of the respondents said that the distance travelled is longer than it used to be in the last 20 years as a result of climate variability. However, 18.8 % of the respondents said that the distance had not changed**.** Focus group discussions revealed that the distance covered had increased and at the same time some of the plant species had disappeared. A FGD at Kambi Mbule had this to say:

> *"When we were growing up, wild fruits, seeds and vegetables were plenty. We used to get them near our houses. Today we walk very long distances to get some. There are some which are no longer available as they have been affected by the increasing droughts"*.

This argument was supported by key informants. The reasons for the increase in the distance travelled and for the disappearance of some edible plants included alienation of land to give way for settlement and crop cultivation. There was an indication from focus group discussions and key informants that the Borana and other pastoral communities moved to Isiolo Central Division as a result of frequent droughts and famines leading to the deaths of livestock. Consequently, they settled in town where they could get relief food and health services from the government. Overgrazing is also associated with the disappearance of wild fruits, seeds and vegetables. The last reason is deforestation as people cut down trees for construction and for fuel wood.

Role of women in searching for wild edible plants for the family

This study indicated that collection and gathering of wild edible plants was mainly undertaken by women as indicated by 70 % of the respondents. Twenty percent (20 %) of the respondents stated that it is the work of children, while 10 % of the respondents indicated that men also collected edible plants. A case was given of herders who ate wild plant products while herding livestock and by the time they reached their homes they were already satisfied. Women were highly associated with the activities of gathering WEP since it is their responsibility to meet household food and fuel needs. As they looked for fuel, they came across these plants even if their intention was not to look for food.. According to the findings of this study, climate variability has doubled the burden of women since they travel long distances in search of these foods for their families especially during times of drought and famine. Respondents revealed that environmental changes brought by climate variability have impacted on gender-based roles, increasing the workload for women. Figure two gives a summary of the outcome.

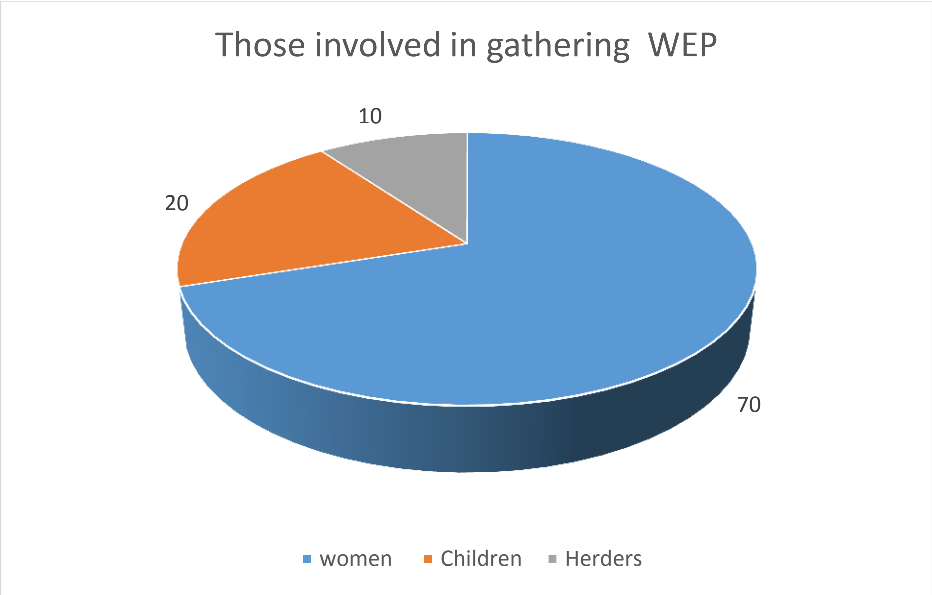

Figure 2. Involvement in gathering wild edible plants

Wild plants which have emerged

On whether there were some plants which had emerged due to climate variability, a majority (63 %) of the respondents stated that there were, while 37 % were of the opinion that there were none. The plants mentioned include; Biscuit *Mjinga (Prosopis juliflora)*, commonly known as *Mathenge*, *gurbi (Acalypha sp)*, *anno (Euphorbia trucalli)*, *leuceana* (L*eucocephala*) and *calliandra (Calothyrsus*). All these plants which have emerged in the study site are not suitable for human consumption but are all suitable for livestock consumption. However, focus group discussants indicated that they had negative attitudes towards the utilization of *Prosopis juliflora* saying that they had heard that the plant was harmful to livestock and human beings. Other plants which were perceived as important by the focus group participants and key informants are *leuceana* and *calliandra*. These are multipurpose plants used for fodder and fuel-wood. According to the findings of this study these plants were introduced by the Ministry of Agriculture in an effort to promote agro-forestry practices in the region. Although there were fodder trees and shrubs which had emerged and others introduced as a result of climate variability, they were few and in small quantities. Thus, they could not be relied on to feed the livestock populations as severe and frequent droughts do not give them sufficient time to recover**.**

Conclusion and Recommendations

The results of this study indicated that wild edible plant products were occasionally used as food by the Borana of Isiolo County during droughts. The respondents indicated that during droughts and famine, pastoralists collected wild foods such as roots, tubers, leaves, seed on a regular basis and this work was done particularly by women and children. This study indicated that the wild plants have been affected by climate variability and this is supported by 88.5 % of the respondents who stated many of the plants have disappeared. The respondents also reported that the distance travelled to gather these plants had increased a great deal as shown by 83.1 % of the respondents. This study came up with two recommendations: the need to train livestock keepers on appropriate coping strategies which are sustainable, and thhe need for pastoral communities to be trained on the best methods of conserving these wild edible plants.

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Land Cover Changes and its Effects on Streamflows in the Malewa River Basin, Kenya

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Abstract

Vegetated landscapes are transformed by both natural and human causes. This is thought to influence river flow regimes. It is argued that restored and reforested landscapes increase stream flow. However, studies done to date have been inconclusive on whether or not trees on restored or reforested landscapes increase stream flow. This study aimed to examine the effects of land cover changes on streamflow of the Malewa River Basin in Kenya. Satellite imagery based spatial change detection using ArcGIS 10.1 and ERDAS IMAGINE software was deployed to estimate the land cover changes. Based on projected land cover change data, a multiple regression technique was used to establish the relationship between land cover and streamflow. The results show that at Gauge 2GB01, area under wetland significantly predicted stream flows (b=0.134, t(488) =1.978, p=0.049), with an overall model (R^2=0.018, F(3, 488)=2.976, p=0.031). Area under grassland (b=0.108, t(488)=2.325, p=0.02), shrubland (b=0.112, t(488)=1.976, p=0.049) and amount of rainfall (b=0.533, t(488)=14.048, p=0.000) combined significantly predicted stream flows. Rainfall alone significantly predicted stream flows (b=0.531, t(488)=13.885, p=0.000). Overall, the gains in forest restoration did not specifically influence streamflow except in combination with other vegetation and rainfall. There is need to increase soil cover rather than woody biomass alone in the regulation of stream flows. A systematic response to address the drivers of change in land cover is also needed.

Key words: landscape, streamflow, restoration, land cover

Introduction

It is not clear how forests contribute to water yield. The lack of clarity is informed by several forest-interaction studies (Silveira *et al.*, 2006; Zhou *et al.*, 2010; Ellison *et al.*, 2012; Beck *et al.*, 2013) under different contexts suggesting inconclusiveness on the relationship between forests and stream flows. It is argued that forests at larger spatial scales contribute to increased evapo-transpiration and precipitation (Ellison *et al.*, 2012). Also, while forests may be net consumers of water and competitors for other downstream users, reduced forest cover could increase stream flows (Price *et al.*, 2010). Generally, land use changes and their associated effects are known to impact the hydrology of the catchment area (Bronstert *et al.*, 2002; Foley *et al.*, 2005; Ott and Uhlenbrook, 2004; Tang *et al.*, 2005). Vegetation cover is thought to increase the capacity of catchments, conserve moisture and increase water yield (Lal, 1997). There seems to be a relationship between altered flows and ecological change (Poff *et al.*, 1997); however no evidence existed to show that ecological change was dependent on hydrological change (Poff and Zimmerman, 2010). Surface runoff and river discharge are generally thought to increase with clearance of natural vegetation, especially forests. This was evidenced, for example, in the Tocantins River Basin in Brazil (1960-1995) where an approximately 25 % recorded increase in river discharge was attributed to expanding agriculture and not a change in precipitation (Costa *et al*., 2003). Elsewhere, stream flows of once degraded areas under large-scale land rehabilitation showed improved base flows (Wilcox andHuang, 2010). On the contrary, findings from 12 meso scale catchments (23-346 km^2) in the island of Puerto Rico do not show influence of changes in urban or forest cover on streamflow trends (Beck, 2013).

In the Mara River, Kenya, it was shown that higher flood peaks and faster travel times were experienced in an area that had undergone increased land use pressure (Mutie *et al*., 2006). In the Nzoia river catchment, it has been observed that forests reduce runoff with increased flows in croplands compared to forests. The findings show that as a result of an increase in agricultural area of between 39.6 and 64.3 % and reduced forest land from 12.3 to 7.0 % (1973-2001), runoff increased by 119 % (1970-1985). The authors noted that climatic factors being constant, land cover changes was responsible for the difference in run-off ranging from 55-68 % (Githui *et al*., 2009). In another study in this catchment, arising from agricultural expansion, streamflow was found to increase during rainy seasons but decreased during the dry seasons. Streamflow generally increased with increase in forest cover. However, when the cover reduced to almost zero, increased peak and mean discharge was noted (Odira *et al*., 2010).

Despite the extensive literature on responses of baseflow and recharge to various human impacts (Price, 2011) these findings are inconclusive. Effects of regenerating forests on stream flow is still little known. This study was designed to address the problem of limited understanding on how forests and trees sustain stream flow in a human modified landscape. It contributes to a body of knowledge on land cover classes – water yield relationships. The objective of this study was to analyse the land cover changes and its effects on streamflows in the Malewa River Basin in Kenya.

Method

Study area

The Malewa River Basin (1,760 km^2) is located in the Eastern Africa (Gregory) Rift Valley, Kenya. See Figure 1. It covers Nakuru and Nyandarua Counties and is administratively bordered by Nyeri and Muranga Counties on the east. The Malewa River discharges about 153 million cubic metres (MCM) of water per annum (Arwa, 2001). The river has a dendritic drainage system, with several streams (including Turasha, Kitiri, Mkungi, Wanjohi and Malewa) emerging from the upper catchment. Rainfall ranges between 600 and 1,700 mm, with the Kinangop plateau experiencing a yearly rainfall ranging from 1,000 to 1,300 mm (Becht and Higgins, 2003). The climatic conditions mirror that of the semi-arid areas, with bi-modal rainfall distribution: longer rainy season (March to May) and short rainy season (October to November, February, July and December) (Kamoni, 1988). The potential evaporation is about twice the annual rainfall (Farah, 2001). The mean annual temperature ranges between 16 ^{o}C and 25 ^{o}C. The daily temperatures range from 5 ^{o}C to 25 ^{o}C (Republic of Kenya, 2014). Soils have been influenced by extensive relief variation, volcanic activity and underlying bedrocks (Sombroek *et al.*, 1982); and developed from lacustrine deposits, volcanic and lacustrine-volcanic basements (Girma *et al*., 2001; Nagelhout, 2001). The soils are prone to erosion and compaction (Kiai and Mailu, 1998). Forests and cropland dominates the upper catchment (the Nyandarua range) while livestock grazing is done at the lower catchments (Muthawatta, 2004).

Study design

The study area was sub-divided into three sub-catchments, namely Turasha (Sub-catchment I), Upper Malewa (Sub-catchment II) and Malewa (Sub-catchments II and III combined). Sub-catchment I was mapped to Gauge 2GC04, Sub-catchment II to 2GB0708 and Sub-catchment II and III combined to Gauge 2GB05. The entire basin consisting of the three sub-catchments was mapped to Gauge 2GB01.

Data collection and analysis

Satellite imagery from Landsat MultiSpectral Scanner (MSS) (1973), Landsat Thematic Mapper (TM) (1986) and Enhanced Thematic Mapper Plus (ETM+) (2000) were obtained from the

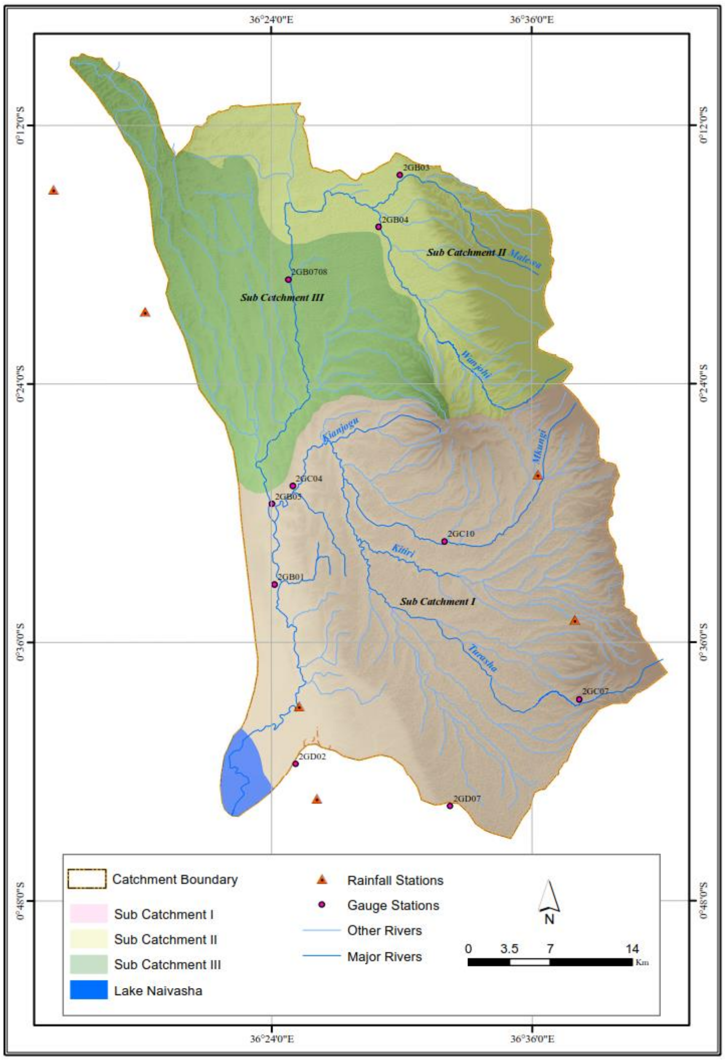

Figure 1. Study area showing location of the gauge and rainfall stations

Landsat database (orthorectified archives) (NASA, 2015). These images were geo-processed using ERDAS imagine 2015 and ArcGIS 10.1 software. SPOT image from Astrium was acquired courtesy of WWF Kenya office. UTM Projection Zone 37N and WGS 84 Datum were adopted in the registration procedures. DeltaCue software was used to perform image registration (ERDAS Inc, 2008). Threshold based segmentation technique where a multilevel image is converted into a binary image (Telgad *et al*., 2014) was applied. Image processing and enhancement was done using ERDAS imagine 2015. An object-based classification using a supervised maximum likelihood classification technique was used. A classification scheme based on Anderson *et al*. (1976) was adopted, with six distinct classes generated, namely cropland, forestland, grassland, shrubland; wetland and settlement. Interpreted raster was then converted into polygons using conversion tool in ERDAS imagine. The normalized difference vegetation index (NDVI) algorithm (Rouse *et al*., 1973) was used to detect vegetation health.

Daily stream flow data for gauges 2GB01, 2GB05, 2GB0708 and 2GC04 (see Figure 1) was sourced from the Water Resources Management Authority. Monthly rainfall data for six stations (9036243 - Dundori Forest Station, 9036029 - Kwetu farm, 9036002 - Naivasha Water Bailiff, 9036081 - National Animal Husbandry Resource Centre, Naivasha, 9036025 - North Kinangop Forest Station and 9036241 - Geta Forest Station) was sourced from the Kenya Meteorological Service.

The land cover data generated for the years 1973, 1986, 2000 and 2013 were then projected using polynomial regression with the data fit achieved using a procedure described in Lutus (2013). It was assumed that area under settlement is part of cropland, and so five class projections was applied. The degree of regression was obtained by setting the number of data pairs minus one. The range was limited to 40 years to match with the study timeframe. To reduce possible bias, the polynomial regression order was set to two. Using XLSTAT software (https://www.xlstat.com/), multiple regression technique was run with the projected land cover class and NDVI against streamflow and rainfall data to establish statistical relationships. Regression equations were used to model the relationship between stream flow and the land cover classes (areas under cropland, forestland, grassland, shrubland and wetland) and rainfall amounts at four gauge stations for the years 1973 to 2013. These gauges represent runoff from four delineated catchments and the rainfall amounts assumed to fall in these areas. The significance level was set at 0.05.

The Pearson Product Moment Correlation (PPMC) (r) (Pearson, 1948) was used to establish the strength of relationship between any two variables: NDVI, land cover classes, rainfall and stream flows.

Results

Rainfall amounts

The monthly rainfall amounts (1970-2013) ranged between 52 mm (2000) and 108 mm (1977) with a mean of 80 mm. The trend in monthly rainfall is provided in Figure 2.

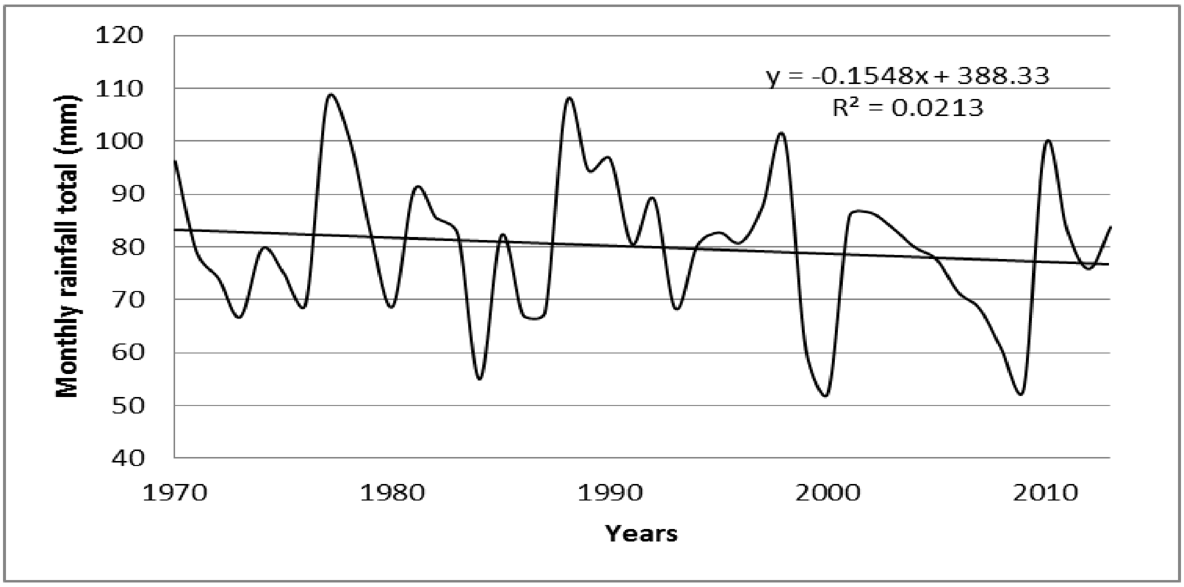

Figure 2. Monthly rainfall trend (1970-2013)

Annual rainfall totals ranged between 627 mm (2000) and 1 293 mm (1977) with an average of 960 mm. The annual trend in rainfall amounts is shown in Figure 3.

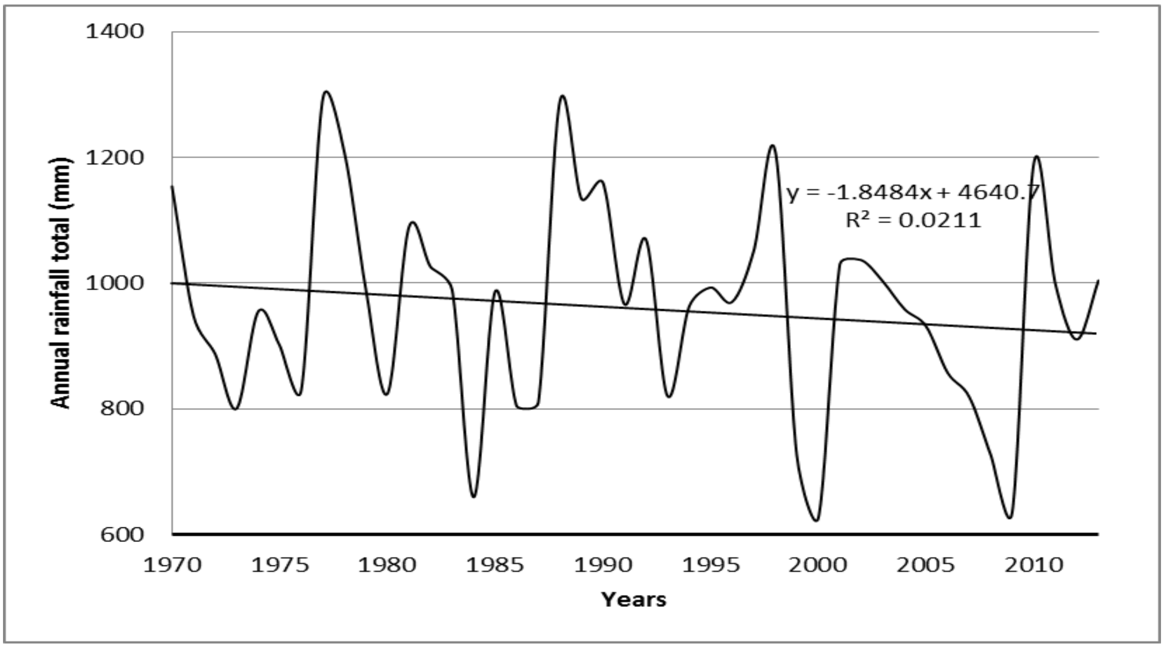

Figure 3. Annual trend in rainfall amounts

Streamflow

On average, the Malewa River at gauge 2GB01 discharges (excluding abstractions) about 191 MCM of water annually. There were wide variations in minimum and maximum diurnal and annual flows recorded in all the four gauges. The daily and annual stream volumes and flow for the four gauges stations (1960-2013) are shown below (Table 1).

Table 1. Daily (m^3/s) and Annual (MCM) Discharges at four gauge stations of Malewa River

Gauge	Mean		Minimum		Maximum		SD	
	Daily	Annual	Daily	Annual	Daily	Annual	Daily	Annual
2GB01	6.1	191.3	0.3	53.1	139.2	358.6	7.1	74.7
2GB05	3.4	106.4	0.3	28.6	115.4	235.7	5.6	47.0
2GB0708	2.3	70.9	0.00	7.6	144.4	186.1	6.1	45.6
2GC04	4.8	150.4	0.00	38.9	136.7	353.0	8.0	67.2

Notes: Daily data in m^3/s; Annual data in MCM

Spatial extents of the three sub-catchments by cover class

Over the years 1973 to 2013, area under cropland increased by 25,589 ha, forestland 4,295 ha and wetland 687 ha. Shrubland reduced by 28,953 ha and grassland 1,751 ha. The spatial extents of the three sub-catchments and land cover classes for the years assessed are shown in Table 2.

Table 2. Area of sub-catchments by land cover classes and years

Years	Sub-catchments	Area of land cover classes (ha)					
		C	F	G	S	W	Se
1973	I	54,298	22,901	4,001	18,628	140	
	II	12,541	14,578	1,735	5,302		
	III	21,996	743	3,389	16,165		
		88,835	**38,222**	**9,125**	**40,095**	**140**	
1986	I	55,516	21,663	5,852	16,651	287	
	II	14,853	13,085	3,906	2,282	30	
	III	24,081	823	13,566	3,803	19	
		183,285	**73,793**	**32,449**	**62,831**	**476**	
2000	I	55,626	18,579	1,326	24,182	237	
	II	16,964	14,319	1,390	1,457	11	
	III	30,016	851	1,909	9,459	43	
		102,606	**33,749**	**4,625**	**35,098**	**291**	
2013	I	58,500	24,938	7,183	8,515	812	3
	II	18,467	14,889		772	13	
	III	37,457	2,690	191	1,855	2	83
		114,424	**42,517**	**7,374**	**11,142**	**827**	**86**

Notes: C=Cropland; F=Forestland; G=Grassland; S=Shrubland; W=Wetland; Se=Settlement. Totals are shown in bold text.

Correlation between variables

The Pearson correlation (PPMC) of projected data on the variables: land cover classes, rainfall, NDVI and stream flows are shown in Table 3. The NDVI values had strong negative correlation with crop land (*r*=-0.740, *p*=0.000), a strong positive correlation with grassland (*r*=0.849, *p*=0.000), a moderate positive correlation with forestland (*r*=0.509, *p*=0.000) and a moderate negative correlation with shrubland (*r*=-0.571, *p*=0.000). As the areas under cropland and shrubland increases, NDVI values decrease and vice versa. However, as the area under forestland and grassland increases, the NDVI values also increases. Grassland had strong negative correlation with cropland (*r*=-0.847, *p*=0.000). As area under grassland increases, that

Table 3. Pearson correlation on the measured variables

	F	R	N	St	C	G	S	W
F	1.000							
R	-.006 (.892)	1.000						
N	**.509**** (.000)	.042 (.351)	1.000					
St	**.098*** (.030)	**.531**** (.000)	.014 (.752)	1.000				
C	**.131**** (.004)	.014 (.752)	**-.740**** (.000)	.078 (.084)	1.000			
G	.013 (.770)	.059 (.189)	**.849**** (.000)	-.022 (.629)	**-.847**** (.000)	1.000		
S	**-.566**** (.000)	-.042 (.348)	**-.571**** (.000)	**-.104*** (.021)	-.010 (.818)	**-.487**** (.000)	1.000	
W	**.616**** (.000)	-.012 (.796)	**-.164**** (.000)	**.129**** (.004)	**.781**** (.000)	**-.416**** (.000)	**-.590**** (.000)	1.000

Notes: F=Forest; R=Rainfall; N=NDVI; St=Streamflow; C=Cropland; G=Grassland; S=Shrubland; W=Wetland

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

of cropland decreases and vice versa. Wetlands had strong positive correlation with cropland (*r*=0.781, *p*=0.000) and a moderate positive correlation with forestland (*r*=0.616, *p*=0.000). Area under wetland increases with increase in cropland and forestland. Shrubland had a moderate negative correlation with forestland (*r*=-0.566, *p*=0.000) and wetlands (*r*=-0.590, *p*=0.000). As the area under shrubland increase that of forestland and wetland decrease and vice versa. A very weak association between forestland and stream flows (*r*=0.098, *p*=0.03), shrubland and streamflow (*r*=0.104, *p*=0.021) and wetlands and streamflow (*r*=0.129, *p*=0.004) was noted. As the areas under forests, shrubland and wetlands increase the magnitude of stream flows also increase. Rainfall and stream flow had moderate positive correlation (*r*=0.531, *p*=0.000). As the amount of rainfall increased, the magnitude of stream flow also increased. NDVI had no correlation with streamflow (*r*=0.014, *p*=0.752).

Influences of land cover changes on streamflow

The relationships between stream flows and land cover classes at Gauges 2GB01, 2GB05, 2GB0708 and 2GC04 are presented in Table 4.

Table 4. Stream flow and land cover classes

Gauge	Model	*b*	*SE b*	*β*	*t*	*Sig.*
2GB01	(Constant)	2.276	5.353		.425	.671
	Area under forestland	4.189E-005	.000	.015	.246	.806
	Area under grassland	2.153E-005	.000	.034	.630	.529
	Area under wetland	**.006**	**.003**	**.134**	**1.978**	**.049**
2GB05	(Constant)	5.347	.875		6.110	.000
	Area under grassland	-1.836E-005	.000	-.039	-.855	.393
	Area under shrubland	**.000**	**.000**	**-.115**	**-2.249**	**.025**
	Area under wetland	-.016	.011	-.072	-1.449	.148
2GB0708	(Constant)	1.378	.776		1.776	.076
	Area under grassland	-.001	.001	-.338	-1.378	.169
	Area under shrubland	.000	.000	.067	.620	.536
	Area under wetland	.126	.077	.334	1.638	.102
2GC04	(Constant)	5.347	.875		6.110	.000
	Area under grassland	-1.836E-005	.000	-.039	-.855	.393
	Area under shrubland	**.000**	**.000**	**-.115**	**-2.249**	**.025**
	Area under wetland	-.016	.011	-.072	-1.449	.148

At Gauge 2GB01, area under wetland significantly predicted stream flows (b=0.134, t(488)=1.978, p=0.049). Area under wetland explained a significant proportion of variance in streamflow values (R^2 =0.018, F(3, 488) =2.976, p=0.031. At Gauge 2GB05 area under shrubland was a significant predictor of stream flows (b=-0.115, t(488)=-2.249, p=0.025), although the model was insignificant. Area under shrubland at Gauge 2GC04 was a significant predictor of streamflow (b=-0.115, t(488)=-2.249, p=0.025), although the model was not significant. The null hypothesis of no significant impacts of the land cover changes on streamflows of the Malewa Rivers was not supported.

Significant predictors of stream flows were: areas under wetlands (2GB01) and shrubland (2GB05 and 2GC04).When combined, grassland and rainfall (2GB01); shrubland and rainfall (2GB05); grassland and rainfall (2GC04) were significant predictors of stream flow. Rainfall alone was a significant predictor of streamflow recorded in all the four gauges. There was no evidence to suggest that forest restoration had significant impact on stream flows.

Influence of land cover changes and rainfall on streamflow

The relationship between land cover classes, rainfall and stream flows for the four gauges are shown in Table 5.

Table 5. Stream flow, land cover classes and rainfall

Gauge	Model	b	SE b	β	t	Sig.
2GB01	(Constant)	1.287	6.288		.205	.838
	Area under forestland	.000	.000	.039	.797	.426
	Area under grassland	**-6.958E-005**	**.000**	**-.108**	**-2.325**	**.020**
	Area under shrubland	**.000**	**.000**	**-.112**	**-1.976**	**.049**
	Amount of rainfall	**.063**	**.004**	**.533**	**14.048**	**.000**
2GB05	(Constant)	**3.123**	**.842**		**3.709**	**.000**
	Area under grassland	-2.794E-005	.000	-.060	-1.409	.159
	Area under shrubland	**.000**	**.000**	**-.103**	**-2.200**	**.028**
	Area under wetland	-.016	.010	-.072	-1.559	.120
	Amount of rainfall	**.027**	**.003**	**.387**	**9.297**	**.000**
2GB0708	(Constant)	1.057	.599		1.763	.078
	Area under shrubland	**-.001**	**.000**	**-.071**	**-2.009**	**.045**
	NDVI values	4.354	3.094	.157	1.407	.160
	Area under wetland	-.016	.027	-.043	-.599	.550
	Amount of rainfall	**.025**	**.003**	**.356**	**8.434**	**.000**
2GC04	(Constant)	-.289	.788		-.367	.714
	Area under forestland	.000	.000	.279	1.716	.087
	NDVI values	**-3.962**	**1.946**	**-.097**	**-2.036**	**.042**
	Area under wetland	-.011	.007	-.250	-1.530	.127
	Amount of rainfall	**.060**	**.004**	**.520**	**13.424**	**.000**

At Gauge 2GB01, area under grassland (*b*=-0.108, *t*(4,487)=-2.325, *p*=0.02), shrubland (*b*=-0.112, *t*(488)=-1.976, *p*=0.049) and amount of rainfall (*b*=0.533, *t*(4,487)=14.048, *p*=0.000) significantly predicted stream flows. Both area under grassland and shrubland, and rainfall combined explained a significant proportion of variance in stream flow values (R^2=0.301, *F*(4,487) =52.47, *p*=0.000). At Gauge 2GB05, area under shrubland (*b*=-0.103, *t*(4,488)=-2.200, *p*=0.028) and amount of rainfall (*b*=0.387, *t*(4,487) = 9.297, *p*=0.000) combined significantly predicted stream flows (R^2 =0.160, *F*(4, 487) =23.235, *p*=<0.000). At 2GB0708, area under shrubland (*b*=-0.071, *t*(4,487)=-2.009, *p*=0.045) and the amount of rainfall significantly predicted streamflow (*b*=0.356, *t*(4,487)=8.484, *p*=0.000), with a significant overall model (R^2=0.136, *F*(4,487) =19.215, *p*=0.000). At 2GC04, area the NDVI values (*b*=-3.962, *t*(4,487)=-2.036, *p*=0.042) and amount of rainfall (*b*=.060, *t*(4,487)=13.424, *p*=0.000) combined were significant predictors of streamflow (R^2=0.272, *F*(4, 487) =45.535, *p*=0.000).

Influences of rainfall on stream flow

In all the four gauge stations, rainfall when considered alone significantly predicted stream flows (Table 6).

Table 6. Influence of rainfall on streamflow

Gauge	Model	b	SE b	β	t	Sig.
2GB01	(Constant)	**1.200**	**.422**		**2.840**	**.005**
	Amount of rainfall	**.062**	**.005**	**.531**	**13.885**	**.000**
2GB05	(Constant)	**1.200**	**.277**		**4.326**	**.000**
	Amount of rainfall	**.027**	**.003**	**.386**	**9.272**	**.000**
2GB0708	(Constant)	.261	.274		.954	.341
	Amount of rainfall	**.025**	**.003**	**.358**	**8.481**	**.000**
2GC04	(Constant)	.121	.419		.289	.773
	Amount of rainfall	**.059**	**.004**	**.514**	**13.279**	**.000**

Discussion

It is demonstrated in this paper that land cover changes had an effect on the quantity of streamflow of the Malewa rivers. Vegetation health was being negatively affected by growth in cropland and demise of shrubland. This however improved when there was growth in areas under grassland and forestland. Changes in grassland affected the intensities of vegetation, and this was influenced by expanding cultivation. It appears that exploitation of wetlands was linked to increase in cropland, implying that much of the land under wetlands was subject to conversion to other uses rather than remaining as water masses. Clearance of shrubland was associated with losses of forests and wetlands, and on the contrary, more forests and wetlands were linked to extensive shrubland. Forestland, shrubland and wetlands were all positively associated with streamflow, meaning, aside from rainfall, these three are the determinants of streamflow. However, wetland and shrubland have significant, though weak relations to streamflow. In the absence of rainfall, shrubland and grassland significantly influenced streamflow. Rainfall had substantial influence on streamflow in all gauges. Surprisingly, NDVI as an indicator of vegetation health did not show influence on streamflow in the lower parts of the catchment. Flows to 2GC04, however, showed evidence of relationship with streamflows, suggesting that the drainage area is still fairly vegetated. These results demonstrate the importance of vegetative cover and not necessarily trees in a landscape. The fact that grassland and shrubland (and to some extent forests) have the ability to increase soil cover means that more water is likely to infiltrate and be retained in the soil sub-surface. Artificial wetlands seem to have been created with conversion to croplands, although forests association with increased wetlands is largely unexplained, safe for the notion that water would be discharged slowly to the wetland.

While these findings seem to confirm those of other similar studies, it is evident that there are still mixed conclusions. Increased stream discharge and surface runoff has been associated with forest cover loss. An increasing trend in annual discharge of the Nyangores river in the upper Mau region has been attributed to land cover change (97.5 %) and climate change (2.5 %) (Mwangi *et al.*, 2016). However, a review of 37 catchments in East Africa show that despite the loss in forest cover about, 63 % of the watersheds had no significant changes in annual discharges while 31 % were showing increasing trends. About half of the watersheds did not show trends in wet seasons and low flows. On the contrary, 35 % had decreasing trends in low flows. It was also established that forest cover and runoff, mean discharge and peak discharge were weakly correlated. The authors conclude that forest cover alone did not present an accurate predictor of streamflow in the catchments (Guzha *et al*., 2018). This finding is in line with that from this study. In a similar study in the wider Lake Naivasha basin, it was noted that due to upstream landscape changes driven mainly by population increase, there was an increase in total runoff despite no changes in rainfall. As such, monthly total runoff volumes increased significantly ($p < 0.01$) by up to 32 % (Odongo *et al*., 2014).

As reported in the WeruWeru Kiladeda sub-catchment of the Pangani Basin, following a decrease in forest and agricultural land due to increased urbanization, shrubland and bare land (1990 to 2009), river flow showed a low dry season and peak wet season flows (Chiwa, 2012). Due to deforestation, land fragmentation, cultivation of wetlands and rapid increase in human settlements, streamflow and ground water reduced in the eastern Mau (Kundu *et al*., 2004). Baseflow was found to decrease due to combined effect of human and natural factors in the River Enjoro catchment (Chemelil, 1995). In the Ewaso Ngiro South River, upper catchment forest cover and number of rainy days declined while there was a general increase in mean annual rainfall (Kiura, 2009). It has been explained that an increase of shrubland allows less infiltration of water due to crusting of the soil which causes both higher peak flows and an increase in total volume of discharge. Cultivated land allows less infiltration than forest, and is often more prone to runoff and overland flow (Gumindonga, 2010).

Conclusions

It is evident that wetlands, shrublands and grasslands played important roles in sustaining streamflow. Wetlands have the ability to slowly release water downstream. Grassland and shrubland increase soil cover therefore water is likely to infiltrate and be retained in the soil sub-surface.

This study recommends the following interventions:

- As rainfall is key to streamflow yield, it is important to manage ecosystems beyond the immediate catchment.
- Manage trends in stream flows by adequately establishing vegetation cover to slow down the flow and increase infiltration. This requires intensifying activities such as planting of grasses, cover crops and woodlots.
- Implement participatory scenario planning to manage different stakeholder expectations on land use. Expansion of cropland and mitigation of losses on shrubland and forests is suggested to intensify sustainable agricultural production through a scheme of optimal land use applying sustainable land use practices such as agroforestry and woodlots that have economic returns to the farmers.
- Further studies are needed to ascertain the quantum contributions of land cover change and climate variables on stream flows at specific restoration sites; and to determine seasonal influence of land cover changes on streamflows.

Acknowledgement

We are grateful to WWF Kenya, Astrium and National Aeronautics and Space Administration for the use of satellite images. Thanks to Water Resources Management Authority and the Kenya Meteorological Service for providing relevant data. Also this work benefitted from the use of ESRI analytical software.

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Degradation Status and Rehabilitation Intervention Potential in Dadaab Sub-County, Kenya

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Abstract

Over exploitation of plant vegetation resources in Dadaab Sub-County has intensified since the establishment of refugee camps from 1991. In 2014, a study was undertaken to map degraded sites and document potential rehabilitation interventions. The study also evaluated the growth of indigenous trees planted for rehabilitation. Study methodology combined use of remotely sensed images to generate change detection maps for the regions from the year 1990 to 2014. This was followed by ground truthing in which plant inventory was carried out in the identified vegetation categories. Also, focus group discussions were conducted with the host population. The results revealed five vegetation categories: dense, moderate, scarce, riparian, and bare land and settlement. After ground truthing these vegetation categories were reclassified as least degraded (dense and moderate vegetation), moderately degarded (scarce vegetation) and highly degraded (bare lands and settlement). The least degraded areas had 634 stems per hectare, moderately degraded 234 stems per hectare and the highly degraded 79 stems per hectare. The presence of bare land surrounding the refugee camps and at watering points were some of the degradation indicators. Access to firewood and building material was increasingly becoming difficult close to the camps and closest settlements. stem a planted rehabilitation tree stand was 850 per hectare at 19years. The study recommends that more effort and resources be committed to promote use of energy conservation technologies within and around the camps and also up-scaling tree planting giving priority to those performing well in the green belts. *Prosopis juliflora* can readily supply biomass fuel and construction material.

Keywords: Daadab, degradation, rehabilitation, refugees

Introduction

Dadaab has been in the lime light around the globe as the town hosting the largest refugee population in the world. It is located in Garissa County, Kenya about 140 km east of Garissa town and 100 km from Kenya-Somali border. The region has a flat topography with altitude ranging from 70 to 400 meters above sea level (m.a.s.l.). The climate of Daadab is classified as semi-arid with annual mean temperatures ranging between 38 °C and 42 °C. It experiences a bimodal rainfall regime with long rains occurring in March to April and the short rains in October to December. The long-term average rainfall is 250 to 300 mm. The rainfall is highly unreliable with some short periodic torrential downpours which do not help in regeneration of pastures. The potential annual average evaporation oscillates between 2100 and 2500 mm. The area was sparsely populated (1 to 2 persons/km^2) and was traditionally under very extensive pastoralism which did not disturb the ecosystem. Soils are usually shallow with a high sand content and slight alkalinity (pH 7 to 8) with poor nutrient levels. Garissa County falls within the semi-arid zone with extensive woodland vegetation type. This comprises deciduous microphyllous bushland and thicket dominated by spiny species of *Acacia* and *Commiphora*. The canopy is rarely taller than 10 m, but is often only 3 to 5 m high and sometimes quite dense. Grasses surprisingly generally contribute little to the biomass. Other common woody plants include *Grewia* species, *Balanites* and various members of the Capparidaceae/Capparaceae family such as *Boscia* and *Cadaba* (White, 1983; CIFOR, 2010).

The Dadaab refugee camps were established in 1991 to house Somali refugees as a consequence of war in Somalia. Three of the camps (Hagadera, Ifo and Gagahaley) were the first to be constructed. Ifo 2 and Kambioos were established later. The Ifo, Ifo 2 and Dagahaley are located in Lagdera (Dadaab) district while Hagadera and Kambioos are located in Fafi district. Hagadera, Ifo, Ifo 2, Dagahaley and Kambioos are all situated within a radius of 18 km. In 2011, the Kambioos refugee camp was established when some 130,000 refugees arrived, fleeing drought and famine in southern Somalia. All the camps were initially intended to be temporary facilities to host 90,000 refugees. However, the camps which have persisted to date host over 360,000 refugees (http://www.researchkenya.or.ke/api/content/abstract/Dadaab+Refugee+Camp%2C+Kenya). Estimates state that refugees in the camps have around 30,000 goat/sheep; 9,000 cows; 3,500 donkeys and 500 camels. Both the human and livestock population have put a lot of pressure on natural resources. The prolonged refugee stay in Dadaab has resulted in severe environmental degradation since the area is a fragile ecosystem that initially sustained a sparsely populated pastoral community. The confined refugees have to be provided with the most basic needs including water, food, shelter and firewood. When some of it, especially firewood and shelter construction materials, are not adequate, the refugees are compelled to source for it from the neighborhood. This creates conflicts with the host community. The major environmental concern since the establishment of the camps is unsustainable harvesting of firewood to meet high cooking energy demand in the camps. The firewood is not only sourced in Dadaab sub-county but also in other areas of the County, causing massive degradation of the environment. The current study was undertaken to document the extent of degradation and propose remedy in the Sustainable Landuse Management project (SLM) sites (Saretho, Dertu, Werhar, Kumahumato and Alkune) within and without Dadaab Sub-County.

Objective

To undertake baseline studies of plant species richness across degradation gradient in and around the Dadaab refugee complex

Materials and Methods

Land cover change degradation assessment in Dadaab Sub-county

In undertaking baseline studies of plant species richness across the degradation gradient and degradation assessment in Daadab Sub-County, an integrated approach which combined geospatial and socio-economic methods was adopted. Remote sensing, a method of spatial data acquisition was adopted due to its repetitive capability which is one of the major concepts required in achieving the said objective. Remotely sensed images were used to generate change detection maps for the regions from the year 1990 to 2014. The selected period was informed by the availability of data sets which also coincided with the period when there was initial influx of refugees (1990).

Satellite images were downloaded from USGS, (http://earthexplorer.usgs.gov/) website, which are provided free and are arranged in rows and paths. Daadab region lies within the path 166 and row 60. The images used were for the years 1990, 1995, 2003 and 2014 (Table 1).

Table 1. Images used for change detection

Year	Sensor	Image id	Date of acquisition
1990	Landsat 4 MSS	LT41660601990138AAA02	18th May 1990
1995	Landsat 5 MSS	LT516606019950478XXX01	17th February 1995
2003	Landsat 7 ETM	LE71660602003030SG500	30th January 2003
2014	Landsat 8 OLI	LC81660602014276LGN00	3rd October 2014

Radiometric and Geometric Corrections

When using satellite imagery to detect change, imagery must be coregistered and radiometrically corrected. Image registration ensures that multidate images from the same path and row are registered to each other within one pixel by onscreen identification of common features, such as road intersections. If pixels do not correctly correspond, then changes due to mis-registration will occur on the final change map. All image data from the USGS have been georeferenced using the same coordinate system. The images were geometrically corrected.

Sub-setting and masking was then undertaken on the processed images using the study area data, Dadaab region, which had been delineated based on past reconnaissance survey.

Image classification

In change detection, several approaches have been widely adopted depending on the availability of resources, technical know-how, the accuracy required and natured or geomorphological orientation of the study area. Some of these approaches include image classification, image transformation and pixel or object-based image analysis.

In this study, supervised classification which requires a priori (already known) information about the data was adopted. Due to the scanty nature of vegetation cover and low population in this region due to low rainfall, major land cover classes identified and of main interest included vegetation (grass and shrubs) and built areas.

In supervised training, we rely on our own pattern recognition skills and a priori knowledge of the data to help the system determine the statistical criteria (signature) for data classification. Classification was performed to highlight vegetation and built areas within the study area. Training sets were developed and spectral signatures from the specified areas were generated. These signatures were then used to classify the pixels using maximum likelihood parametric decision rule. Change detection using the compute difference algorithm was applied. Firstly, change between the images 1990 and 1995, then for 1995 and 2003 and finally for 2003 and 2014.

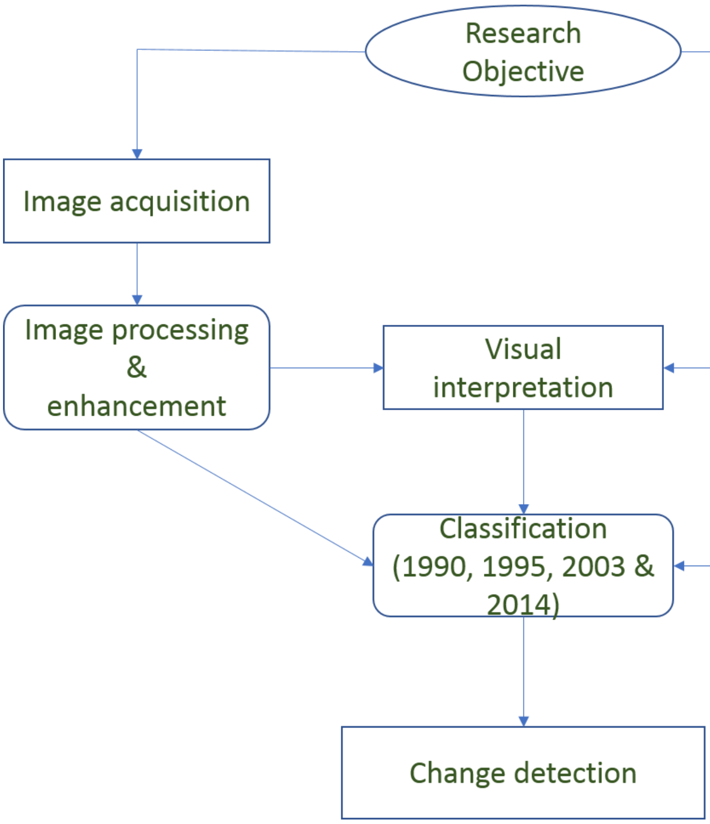

Figure 1. Methodology for Change detection

Ground truthing and assessment of baseline vegetation resources

Ground truthing was subsequently carried out to determine conditions of change guided by hand-held Global Positioning System (GPS). A stratified random design was used where by sample plots were randomly generated using QGIS version 2.4 in each of the three degradation categories (Least degraded (dense + moderate vegetation categories); Moderately degraded (scarce vegetation category) and Highly degraded (Bare land and settlement). The UTM coordinates were then uploaded into a GPS receiver to guide ground navigation sample plots. These same sample plots were used for vegetation assessment. After navigating the sample plots, the primary reference coordinates loaded into a GPS were used as plot centers.

One of the team members remained stationery at the plot center to guide plot establishment by the field crew. Using reference north and bearing of 45°, 135°, 225° and 315° to locate plot corners, a plot measuring 20 m x 20 m was laid out using a tape measure (Figure 2). Additional data was obtained from local informants through focused discussions and field observations.

The nested plot design similar to that used by Mengistu *et al.*, *(*2005) was adopted to collect data on trees, shrubs, saplings, seedlings and herbaceous species. The design consisted of the inner sub-plot of 2 m × 2 m (0.0004 ha) nested at the centre, used for identification and estimation of percentage ground cover of all herbaceous species and seedlings (woody plants less than 0.5 m tall). The 5 m x 5 m (0.0025 ha nested at the center for identification and height measurements of saplings of woody plants (a tree more than 0.5 m height and diameter at breast height (DBH) less than 2.5 cm). The plot was also used for identification and percentage cover of all the shrubs. The big 20 m x 20 m plot (0.04 ha) was used for plot level assessment, namely; general plot details such as slope angle/direction, disturbance level, landscape position and measurements of height and diameter at breast height (DBH) of all trees (woody plants with height above 2 m and DBH of at least 2.5 cm). For forked trees, each stem was treated as a tree provided the stem branching occurs below 1.3 m.

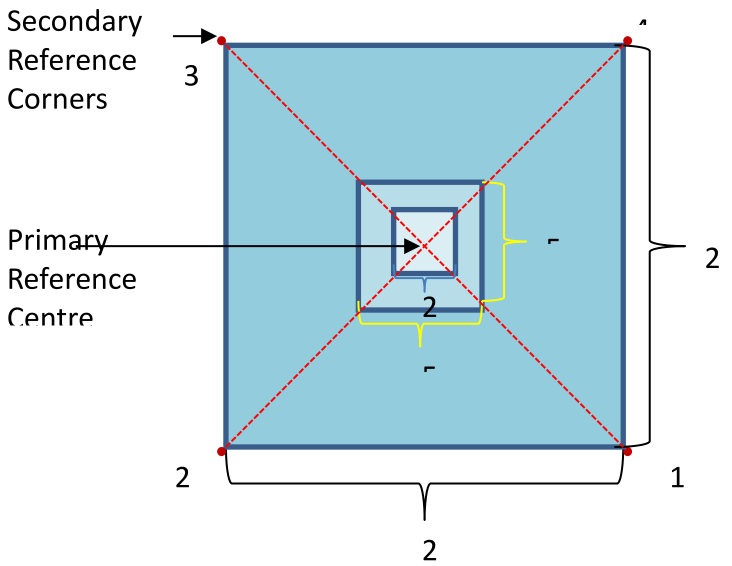

Figure 2. Sampling design for the vegetation

After data collection the following parameters constituting population structure were computed:
Population structure has been used widely to study regeneration patterns in natural forest ecosystems (Tanouchi and Yamamoto, 1995; Mekuria *et al.*, 1999; Rocky and Mligo, 2012). Hence, diameter at breast height (DBH) size distribution was used to assess regeneration status of forests along delineated degradation gradient. Species diversity, density, basal area, frequency and other derived ecological variables and indices were calculated using standard formulas (Magurran, 1988). Some of the derived variables were as follows:

- Stocking level: Number of stems per hectare. This is given by addition/summation of trees in the sample plots divided by the total area of the sample plots.
- Basal area (BA): The cross sectional area of each tree stem measured at 1.3 m above the ground. This value is normally obtained using the following equations:
  BA = π * (DBH/2)2
  π= 3.14

DBH = Diameter at beast height.

Within the plot,

- Relative dominance: Basal area of a given species divided by the sum of the basal areas of all of the species * 100.

- Frequency: The number of plots in which a given species is found divided by the total number of plots sampled.

- Relative frequency: Frequency of a given species divided by the sum of the frequencies of all the species * 100.

- Density: The total number of individuals tallied for a given species divided by the total area of the measured plots (plants per hectare)

- Relative density: Density of a given species divided by the sum of the densities of all of the species* 100.

- Importance value index (IVI): Relative frequency + Relative density + Relative basal area for each species

- Shannon diversity Index (*H'*): This was obtained using the following equation:

$$H' = -\Sigma pi \ln pi$$

Where, *i* is the proportion of the species relative to the total number of species (*p*i) multiplied by the natural logarithm of this proportion (ln *p*i) and the final product multiplied by -1.

The index assumes that each representative sample species has an equal chance of being included in each sampling point. This method was selected because it provides an account for both abundance and evenness (Magurran, 1988). It also does not disproportionately favour some species over the others as it counts all species according to their frequencies (Lou, 2006).

Assessment of the planted stands

There are several planted stands within and around the Daadab refugee camps complex. Three of these stands were assessed for growth. These are located at Hormud, Liboi road and at the central nursery. The stand at Liboi road and the other at Central nursery were planted by the Relief, Reconstruction and Development Organization (RRDO) in 2004 and 2005 respectively, the Hormud stand was planted in 1996 by the German Organisation for Technical Cooperation (GTZ).

Results and Discussion

Changes of vegetation

Five vegetation classes were identified; dense, moderate, scarce, riparian, and bare land and settlement. The dense woody vegetation captured by image in 1990 prior to the influx of the refugees was about 33 % of the total land mass under survey (1, 969, 358 ha). It progressively decreased to slightly above 13 % by 2014. The areas covered by moderately dense vegetation remained the same between 1990 and 1995 after which it increased from 20 to 25 % by 2003 then it decreased slightly by 2014 (Figure 3). Bare land and settled land increased by over 50 % between 1990 and 2014 (Figure 3). There was a slight increase in areas with scarce vegetation from 20 to 25 %. These changes can be attributed mostly to the influx of refugees from Somalia in 1991 and 2011.

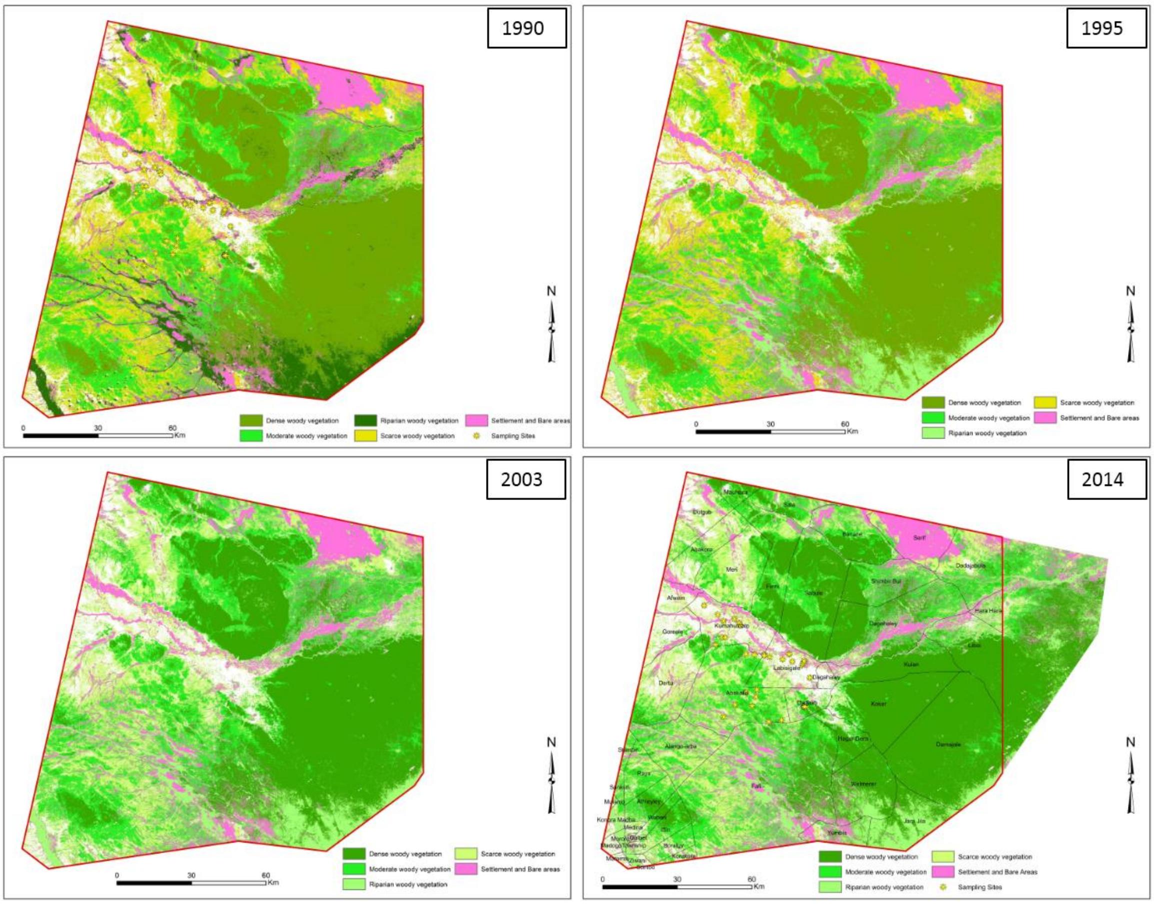

Figure 3. Satellite images showing vegetation changes in and around Daadab between 1990 and 2014.

To accommodate more than 130, 000 refugees in 1991 and which had increased to over 360, 000 by 2012, land was cleared to create space. More wood was harvested for construction and fencing. Fuel wood was initially supplied from dead wood collected from in and around Daadab by the United Nations High Commission for Refugees (UNHCR). At first the fuel need was met with ease but with increase of refugees the dead wood became more and more scarce and large areas had to be combed to get enough. Eventually harvesting of green wood creeped in secretly, in that the green wood mostly *A. reficiens* was harvested and left in the field to dry before making official delivery to the camp. This has contributed to the degradation of woodlands and has resulted to the increase of the proportion of vegetation under moderate and scarce categories. The refugees had over 40, 000 heads of livestock that increased grazing pressure on the land by competing with over 500, 000 heads of livestock from the host community (World Bank 2010). In addition there was increased level of sedentarization by the host community in Daadab and in the surrounding villages such as Saretho, Welhar, Alkune Kumahumato and Dertu. This has resulted to more land being cleared for construction and supply of fuel wood. Also all the sites surrounding the watering points were totally stripped of vegetation. As a result during the wet season there is increased level of soil erosion leading to destruction of some areas with riparian vegetation.

Species composition and diversity

A total of 31 plant species belonging to 12 families were identified in 31 sample plots assessed. The plant composition consisted of 22 tree species, 5 shrubs, 2 herbs and 2 grasses. Burseracea and Mimosaceae were the families with the highest number of species with six and five species respectively. Family Capparaceae had four species while Salvadoraceae, Malvaceae, Lythraceae and Combretaceae each had two species and two families had one species each. There were 18 different mature tree species in the least degraded areas with a mean stem density of 634 per hectareand basal area of 2.53 m^2. This stocking density lies within the reported density range of 300 to 900 stems per hectarefor the dry forests and woodlands of Africa (CIFOR, 2010). Daadab vegetation is less diverse compared to the vegetation of Samburu district that had 165 plant species from 46 families (Makishima, 2005). The mean stem density of the moderately degraded areas was 239 per hectareand the corresponding basal area of 1.6 m^2 per hectare. The highly degraded areas had nine different species with mean stem density of 79 per hectareand basal area of 0.02 m^2 per hectare. The low density of trees in the highly and moderately degraded areas can be attributed to clearing woodland for construction, extraction of wood for construction, fencing and for fuel wood.

The Shanon diversity index of mature trees was highest (2.21) in the least degraded and least (1.67) in the moderately degraded areas (Table 2). The sapling population density and Shanon diversity index was highest in the moderately degraded areas and lowest in the highly degraded areas (Table 2). No seedling of woody plants was found across the degradation gradient. This can be attributed to mortality from overgrazing and trampling by livestock since grazing was widespread in the study areas. According to the locals, fewer and fewer trees are flowering and producing mature fruits due to reduced/shortened wet seasons and more frequent and prolonged severe droughts. They indicated that the availability of pods and other types of fruits which form part of diet for their livestock was becoming rare. This could have impacted negatively on the available soil seed reserve and thus natural regeneration.

Table 2. Woody plant species diversity and density along degradation gradient

Degradation category	Saplings			Trees		
	H´	Density per hectare	Species richness	*H´*	Density per hectare	Species richness
Low	0.96	255	3	2.21	634	17
Moderate	1.1	343	3	1.67	239	7
High	0.69	64	2	1.94	79	9

The mean height of most species in the Mimosaceae family varied between 2.5 to 5.5 m while most species of the genus Commiphora were generally short being less than 4 meters tall. This is in agreement with the description of White (1983).

Tree species important value index (IVI) along degradation gradient

The IVI has been used in various studies to show ecological importance of species in a given ecosystem (Kigomo *et al.,* 1990; Kacholi, 2014: Kigomo *et al.*, 2015). In the low degraded areas, *C. candedula* had the highest IVI followed by *Terminalia polycarpa,* which had a low relative frequency (4.44 %) but a high relative dominance. *Salvadora persica* had the least IVI. *Acacia reficiens* the most highly valued fuelwood species in the refugee camps ranked fourth most important species but in the moderately and highly degraded areas it was not found (Table 3). This species may have been selectively extracted to depletion in the moderately and highly degraded sites. *Commiphora candedula* was also the most important species in the moderately and highly degraded areas partly due to its high relative dominance and relative frequency. It was noted that as degradation became more severe, the IVI of Commiphora spp (Burseraceae) became higher and higher (Table 3). This could be due to their low utility as fuel wood and as construction material and therefore rarely harvested except for a land use change.

Table 3. Tree species based on IVI (important value index) along degradation gradient (RF: Relative Frequency, Rdom: Relative dominance, Rden: (Relative density).

Tree species/degradation category					
Low degradation		**Derived Ecological variables**			
Botanical name	**Family**	**RF**	**Rdom**	**Rden**	**IVI**
Commiphora candidula	Burseraceae	20.000	29.023	14.533	63.556
Terminalia polycarpa	Combretaceae	4.444	24.976	5.536	34.957
Commiphora africana	Burseraceae	11.111	0.055	20.761	31.928
Acacia reficiens	Fabaceae	15.556	3.639	12.457	31.651
Commiphora edulis	Burseraceae	2.222	21.766	1.384	25.372
Terminalia brevipis	Combretaceae	2.222	0.255	20.415	22.892
Dobera glabra	Salvadoraceae	6.667	4.765	3.806	15.238
Balanites aegyptiaca	Balanitaceae	4.444	0.184	9.343	13.971
Ficus spp	Moraceae	2.222	3.488	0.346	6.056
Cadaba gladurosa	Capparaceae	4.444	0.346	0.692	5.483
Cadaba falinosa	Capparaceae	4.444	0.150	0.692	5.287
Acacia nubica	Fabaceae	2.222	0.103	0.692	3.017
Cadaba rotundifolia	Capparaceae	2.222	0.272	0.346	2.840
Salvadora persica	Salvadoraceae	2.222	0.143	0.346	2.711
Moderately degraded					
Commiphora candidula	Burseraceae	35.294	44.781	19.118	99.193
Acacia zazibarica	Fabaceae	23.529	15.072	39.706	78.307
Commiphora holtziana	Burseraceae	41.176	20.690	8.824	70.690
Dobera glabra	Salvadoraceae	52.941	5.564	4.412	62.917
Commiphora spp	Burseraceae	47.059	1.391	7.353	55.803
Commiphora africana	Burseraceae	29.412	9.467	11.765	50.643
Acacia mellifera	Fabaceae	17.647	2.159	7.353	27.159
Heavily degraded areas					
Commiphora candidula	Burseraceae	58.333	16.572	24.390	99.296
Commiphora holtziana	Burseraceae	66.667	9.107	19.512	95.286
Commiphora spp	Burseraceae	75.000	4.315	9.756	89.072
Commiphora africana	Burseraceae	50.000	25.170	9.756	84.926
Acacia tortilis	Mimosaceae	16.667	42.153	17.073	75.893
Cadaba falinosa	Capparaceae	33.333	1.959	9.756	45.048
Cadaba gladurosa	Capparaceae	41.667	0.124	2.439	44.229
Boscia coriacea	Capparaceae	25.000	0.519	4.878	30.397
Acacia nubica	Mimosaceae	8.333	0.081	2.439	10.853

Acacia tortilis had one of the highest IVI in the highly degraded areas and it had a high relative dominance. This species could have been spared due to its importance as a source of livestock feed especially during the dry season.

Ground vegetation cover

The ground vegetation cover was highest (18 %) in the highly degraded areas and least (4 %) in the least degraded areas (Table 4). This could be due to the fact that the survey was conducted during the dry season. Also, the areas covered by this survey were overgrazed by the local populations in Daadab and the surrounding villages such as Werhar, Saretho, Kumahumato, Labisigale, Abakaile, Alkune and Dagahale. The livestock population owned by the locals in Daadab is about 80 to 100,000 camels, 200 to 250, 000 cattle and 300 to 350,000 goats (Mwangi, 2017). The refugee population also had quite large population of livestock (40 000 camels) competing for grazing and water with those of the locals (World Bank, 2010). The ground vegetation cover in the highly degraded site was primarily made of *Enteropogon spp* (10 %) and *indigofera errecta* (5.5 %) (Table (iv)). *Dousperma eromophilum* was found in all the three degradation categories while *Cenchrus ciliaris* was found in moderate and low degraded sites. *Abutilum hirtum, Enteropogon* spp and *Barleria acanthoides* were confined to the highly degraded sites only.

Table 4. The composition of herbaceous vegetation cover across the degradation gradient

Herbaceous species/ degradation category	**Family**	**Cover (%)**	**Relative frequency**	**Habit**
High degradation				
Abutilum hirtum	Malvaceae	0.5	7.69	shrub
Barleria acanthoides	Acanthaceae	0.5	7.69	herb
Dousperma eremophilum	Acanthaceae	0.5	7.69	shrub
Enteropogon spp	Poaceae	10.0	15.38	grass
indigofera errecta	Fabaceae	5.5	7.69	shrub
Sida tenuicarpa	Fabaceae	0.75	15.38	shrub
Moderate degradation				
Cenchrus ciliaris	Poaceae	0.5	14.29	grass
Dousperma eremophilum	Acanthaceae	5.0	14.29	shrub
Indigofera spinosa	Papilionaceae	1.0	14.29	herb
Low degradation				
Cenchrus ciliaris	Poaceae	0.5	12.50	grass
Dousperma eremophilum	Acanthaceae	0.5	12.50	shrub
Indigofera spinosa	Fabaceae	0.5	25.00	herb
Punica spp	Punicaceae	2.0	12.50	shrub
Seddera hirsute	Convovolaceae	0.5	12.50	shrub

In addition, the highly degraded sites had slightly a higher species richness mainly composed low shrubs compared to the other sites. This could be due absence or reduced competition due to removal of big tree and shrubs. It could also be a natural feedback mechanism to recolonize the site naturally.

Tree diameter size class distribution in Daadab

In all the three degradation categories, DBH distribution exhibited inverted J-shaped pattern with most of the trees in the smaller size classes and fewer in the larger size classes (Figure 4, 5,6). The small size classes of trees with a DBH of below 12.5 cm was represented with 97, 85 and 79 % for low, high and moderate degradation categories respectively.

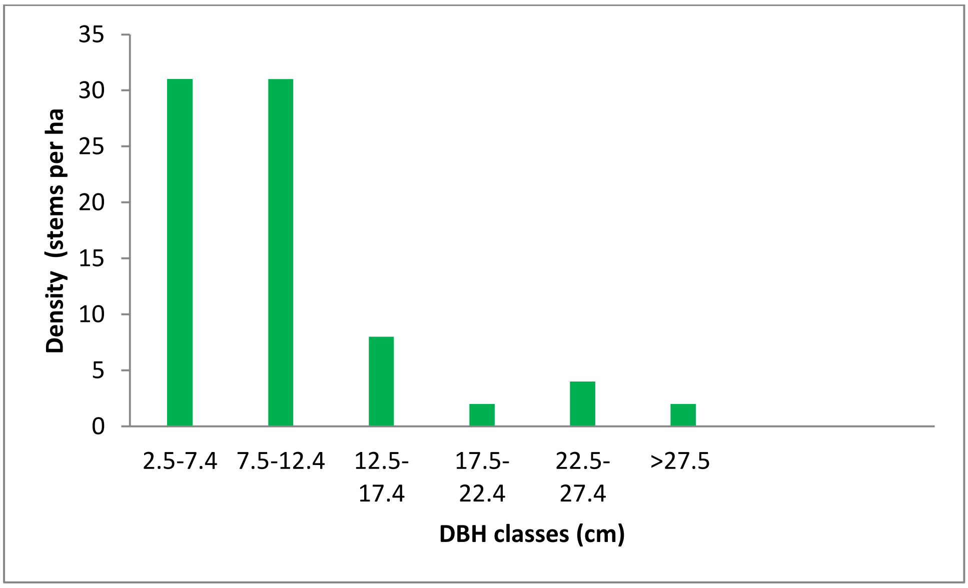

Figure 4. Size class distribution of tree species in the least degraded areas

The inverse J-shaped curve for the moderately degraded areas started at the second lowest diameter class, the lower numbers of trees with small diameters may be the outcome of selective harvesting targeting smaller trees. Alternatively, it could have resulted from low recruitment from saplings into the small DBH class since the population of the saplings found in all the degradation categories was very low and there was no seedling found.

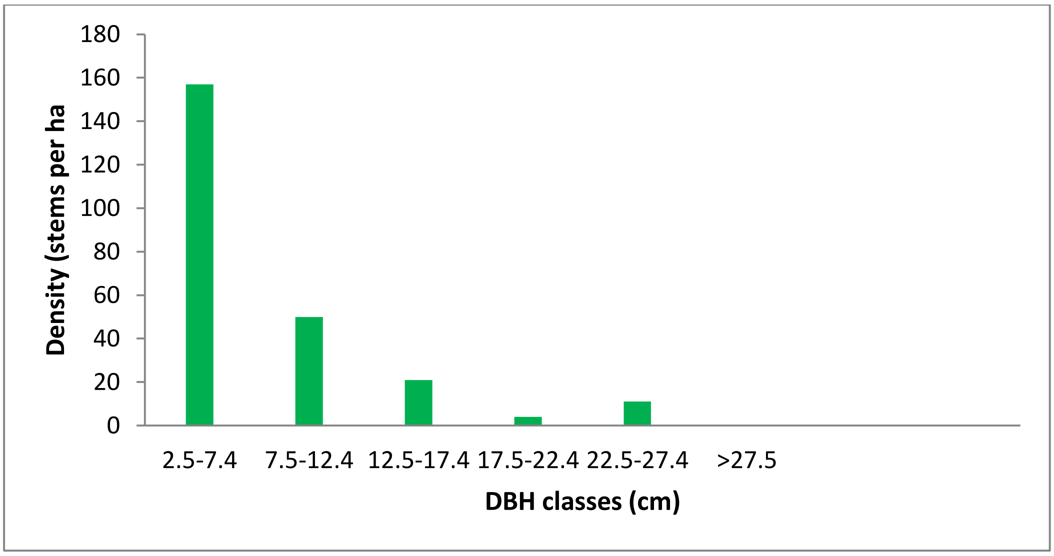

Figure 5. Size class distribution of tree species in the moderately degraded areas

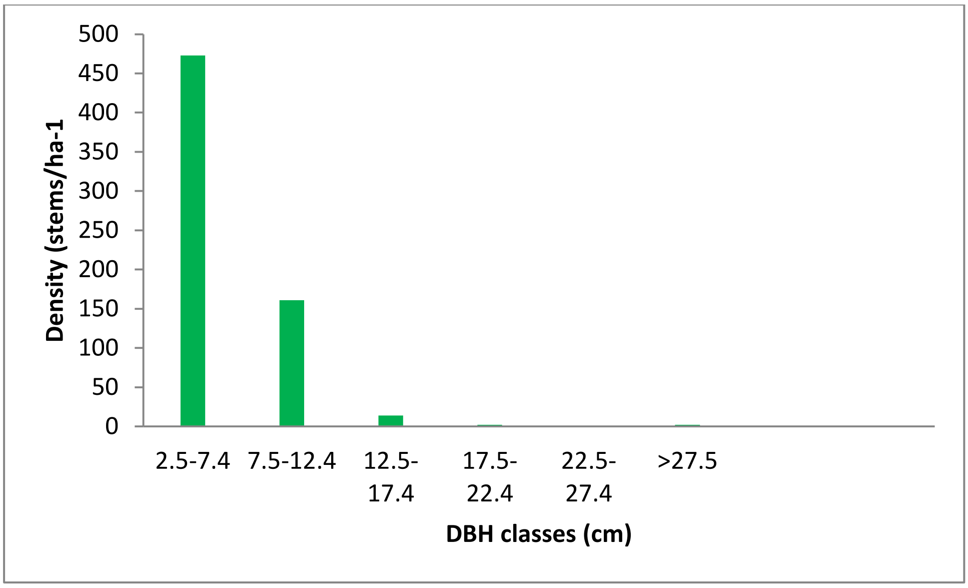

Figure 6. Size class distribution of tree species in the highly degraded areas

Cut Stumps

The highest number of cut stumps was recorded in the moderately degraded areas. The population density was 62 stumps ha^{-1} consisting of *A. mellifera, C. monoica, C. africana,* and *G. tenax* (Table 5). The number of cut stumps in the high and low degraded sites was 59 and 22 stems ha^{-1}, respectively (Table 5). The most cut trees were *C. africana*, C. *myrrha, B. coriacea* and *A. reficiens. Acacia reficiens* was heavily exploited for fuelwood supply to the refugee camps while the small sized sticks of *B. coriacea* were cut for construction. *Commiphora africana* and the other Commiphora spp were mainly cut for fencing. It was not possible to capture the actual number of *A. reficiens* extracted since most of it was extracted by uprooting. There is no law to regulate wood harvesting in Daadab since the land is communally owned. Thus the tragedy of commons prevails. Security challenges further complicates the implementation of measures to arrest degradation and reclaim the degraded areas. The signs of wood extraction in the highly degraded sites were completely concealed due to excessive disturbances of the ground.

Table 5. The composition of cut stumps by species across the degradation gradient

Species/degradation category	Family	No. of Stumps ha^{-1}
High degradation		
Boscia coriacea	Capparaceae	27
Acacia reficiens	Mimosaceae	8
Acacia mellifera	Mimosaceae	6
Acacia tortilis	Mimosaceae	4
Cordia monoica	Boraginaceae	6
Cadaba gladurosa	Capparaceae	2
Grewia tenax	Tiliaceae	4
Cadaba gladurosa	Capparaceae	2
Total		59
Moderate degradation		
Cadaba falinosa	Capparaceae	4
Commiphora Africana	Burseraceae	43
Cordia monoica	Boraginaceae	11
Grewia tenax	Tiliaceae	4
Total		62
Low degradation		
Acacia reficiens	Mimosaceae	2
Acacia melifera	Mimosaceae	9
Commiphora myrrha	Burseraceae	9
Grewia tenax	Tiliaceae	2
Total		22

Performance of the planted stands (Greenbelts)

The stand at Hormud had a stem density of 850 stems per ha consisting of *A. tortilis* and *A. reficiens* (Table 6). The stand along the Liboi road had a stocking level of 75 stems per ha consisting of three tree species while the stand at the central nursery had a density of 500 stems per ha made up of 5 indigenous tree species (Table 6). This stand was invaded by the invasive *Prosopis juliflora*.

Table 6. Growth of planted trees at different sites of Daadab Camps complex

Site	Year of planting	Species	Mean height (m)	MAI
Central nursery	2005	*A. seyal*	3.8	0.422
Central nursery	2005	*A.crata*	4.3	0.478
Central nursery	2005	*A.mellifera*	2.1	0.233
Central nursery	2005	*A.nubica*	2.4	0.267
Central nursery	2005	*A.senegal*	4.03	0.448
Central nursery	2005	*A.tortilis*	3.05	0.339
Central nursery	2005	*Prosopsis*	3.05	-
Hormud	1996	*A.reficiens*	3.88	0.216
Hormud	1996	*A. tortilis*	5.34	0.297
Liboi road	2004	*A. mellifera*	4.9	0.49
Liboi road	2004	*A.senegal*	2.55	0.255

From a meeting held with local community members in June 2014, they proposed *B. aegyptiaca*, *A. mellifera* and *A. tortilis* among others (Table 7) as potential rehabilitation species. Most of the proposed rehabilitation species are sources of fodder for livestock while others such as *C. holtziana* and *Azadirachta indica* are valued for shade. Based on the performance of the planted stands *A. seyal* and *A. senegal* are also potential rehabilitation species.

Table 7. Potential tree and grass species for rehabilitation

Botanical name	**Family**	**Habit**	**Major use**
Balanites aegyptiaca	Balanitaceae	Tree	Fodder
Acacia mellifera	Mimosaceae	Tree	Fodder
Acacia tortilis	Mimosaceae	Tree	Fodder
Cordia monoica	Bovaginaceae	Tree	Fodder
Boscia coriaceae	Capparaceae	Tree	Fodder
Dobera glabra	Salvadoraceae	Tree	Fodder
Commiphora holtziana	Burseraceae	Tree	Shade
Azadirachta indica	Meliaceae	Tree	Shade
Enteropogon macrostachyus	Poaceae	Grass	Fodder

Conclusion

The immigration and settlement of the refugees in Dadaab and the surrounding areas has reduced vegetation cover and number of available plant species in the environment through selective removal.The study recommends that more effort and resources be committed to promote use of energy conservation technologies within and around the camps and up-scaling of tree planting giving priority to those performing well in the green belts and those preferred by the local community. *Prosopis juliflora* can be exploited for supply of biomass fuel and construction material.

Recommendations

The study recommends that more effort and resources be committed to promote use of energy conservation technologies within and around the camps and also up-scaling tree planting giving priority to those performing well in the green belts. The management of the invasive *Prosopis juliflora* should be given priority for supply of biomass fuel and construction material.

Acknowledgement

The authors acknowledge the financial support from GEF/UNDP and Government of Kenya. KEFRI Director and Regional Director of Dryland Eco-region Research Programme (DERP-Kitui) are highly appreciated for facilitating implementation of the project activities. We are also grateful for logistical support received from other partners including KFS, County Commissioner, and State Department of Livestock Development. We also express special thanks to RRDO for allowing us access to their planted stands for data collection. Lastly, special gratitude go to the local communities, who willingly collaborated with project implementers.

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Rangeland Rehabilitation Using Micro-Catchments and Native Species in Turkana County, Kenya

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Abstract: Turkana County is prone to perturbations and famine owing to the prevailing climatic conditions. Due to degradation through nature and anthropogenic activities such as charcoal burning over time, existing woodlands have been degraded necessitating rehabilitation. Several drylands adapted plant species studied over the years which respond aptly to the needs of the communities were identified and isolated through a survey. The study was conducted in Ekalees-Lodwar and the plant species planted were *A. mellifera; A. senegal; A. tortilis; Adenium obesum; Cordia sinensis; Dobera glabra; Parkinsonia aculeata, Salvadora persica* and *Melia volkensii* and were introduced for observation on performance. The study's objectives were to determine the effectiveness of micro-catchments in rangeland rehabilitation and to compare species performance to appraise the species highly adaptable to the environment. This offered an opportunity to demonstrate climate smart technologies regarding rangeland rehabilitation. Micro-catchments were used as treatment where similar number of species of the same age were grown while the control was site without micro-catchment. The major finding of the study was that using micro-catchments gave higher mean heights and root collar diameters for each species tested. The results support the use of micro-catchments especially in arid and semi-arid areas as well as the performance of selected native species in natural ecosystems.

Key words: Micro-catchment, rehabilitation, degradation, native species, Turkana County

Introduction

Globally, land degradation and deforestation in the rangelands are serious environmental challenges currently recognized as threats to the wellbeing of range inhabitants(Yirdaw *et al*., 2017) with 10 to 20 % of these areas being severely degraded (Kimiti *et al*., 2017). The government of Kenya recognizes land degradation as a serious challenge which often causes an annual economic loss of 3 % of the national GDP (MENR, 2016). Given that these dry lands make up 80 % of the Kenya land mass, and support over 60 % of pastoral livelihoods (Wairore, 2015), restoring, maintaining and increasing their productivity is imperative. According to Mwamburi and Musyoki (2010), Kenyan rangelands are characterized by scattered vegetation, low and erratic rainfall, high evapotranspiration and shallow soils with low water holding-capacity, thus favouring pastoral production systems. However, land degradation and deforestation continue to threaten the livelihoods of indigenous communities who entirely depend on the scarce and diminishing natural resource base(Kigomo and Muturi, 2013).

Pastoralists in the ASALs of Kenya continue to face a myriad of challenges due to rangeland degradation, unpredictable weather patterns and environmental mismanagement (Mganga *et al*., 2015). Being an arid area, Turkana County is prone to perturbations and famine owing to prevailing climatic conditions (Republic of Kenya, 2014). Despite the challenges, Turkana pastoralists have over the years sustainably used woodland resources through traditional practices and laws such as delineation of seasonal grazing areas and periodic movement (Muturi *et al.*, 2014a). This practice facilitated the resilience of range resources to withstand shocks and stresses (Kidake *et al.*, 2016). Nonetheless, these traditional practices have currently collapsed owing to the changing dynamics of land use and socio-economic factors.

Seventy percent (70 %) of the inhabitants of Turkana County are pastoralists depending largely on livestock and livestock products for livelihood(Watson and VanBinsbergen, 2008). Moreover, they rely on the native vegetation as a source of fruits and food, and a dry season browse for livestock. Trees growing in ASALs face several challenges including moisture stress, termite infestation, animal damage and competition from weeds (Mwamburi and Musyoki, 2010). According to Muturi *et al*., (2014a), the available woodland resources in the ASALs cannot sustainably meet the increasing demand for fuel wood, charcoal and construction poles thus exacerbating woodland degradation and reduction of both plant species diversity and density. Land degradation is even more serious around settled areas where population has continued to grow drastically.

Forest cover in Turkana County is estimated to be 4% far below the recommended 10% forest cover (Turkana County Government, 2016). Among the contributing factors is the increased human pressure on the woodland vegetation which has created conditions conducive to degradation, deforestation and desertification of the fragile environment(Muturi *et al.*, 2014b). Muturi *et al*., (2014a) argued that woodlands have been degraded necessitating rehabilitation as such areas cannot be left for natural regeneration process. There is therefore the need to beef up forestry in designated settlement areas to act as a buffer zone during dry season and cushion pastoralist from extreme weather conditions.

Rehabilitation of degraded ecosystems plays a vital role in the conservation of threatened and unique dry land biodiversity as well as enhancement of ecosystem services(Yirdaw *et al.*, 2017). Rehabilitation also enhances the adaptive capacity and resilience of local communities and ecosystems to degradation pressure. Several rehabilitation measures to combat degradation and improve pasture availability have successfully been undertaken(Kigomo and Muturi, 2013; Muturi *et al.*, 2014a; Wairore, 2015); with most rehabilitation strategies involving use of enclosures.

The use of micro-catchment technology has been utilized to increase success of various afforestation initiatives in the drylands as it ensures speedy growth of trees and deep root development thus minimizing mortality rate (Ali and Yazar, 2007; Haruna, 2014). This results from the fact that rainfall in arid and semi-arid areas is unreliable, hence trees planted must have some drought tolerant ability and tree properties for their sustainability (Muturi *et* *al*., 2014a). However, there is limited documentation on rangeland rehabilitation using micro-catchments and native species in Turkana County. The establishment of micro-catchment areas in the County as a strategy for rehabilitation significantly provides a platform for promoting regeneration of native plant species to improve forest and ground cover as well as improving communities' livelihoods (Jama and Zeila, 2005).

Micro-catchments are rainwater harvesting structures that collect rainfall runoff and direct it to the planting hole thus improving soil moisture and plant vigour (Haruna, 2014). Water thus harvested is made available to the tree long after the rains have stopped. There are different types of micro-catchments: V-shaped, W-shaped, circular, and semi-circular (Mwamburi and Musyoki, 2010). Thus, semi-circular micro-catchments were used in trials to rehabilitate some areas with much success and various community adaptation.

The objectives of the study were to determine the effectiveness of micro-catchments in rangeland rehabilitation and to compare species performance to appraise their adaptability to the environment. The study provided an opportunity to demonstrate climate smart technologies regarding rangeland rehabilitation to local communities in Turkana County.

Materials and Methods

Study site

The experiment was conducted in a public plot of land in Ekalees, Turkana County, 10 km off Lodwar-Kitale road. The area selected had deep sandy soils. The vegetation was scarce on the site with only two species present: *Balanites aegyptiaca* and *Acacia tortilis*. The entire site was fenced with metal bars and barbed wire to secure it from browse species and had security round the clock to secure the site.

Establishment of research plots

Within the Ekalees plot, a 38 m by 29 m experimental plot was established and fenced. The experiment was laid out on a completely randomized design. Semi-circular micro-catchments (treatments) with spacings of 4 m by 4 m were then constructed within the fenced plot before the rains. Seedlings of mixed species that were propagated at KEFRI tree nursery, Lodwar were transplanted in the plots. The treatments were replicated three times. The control site was without micro-catchments. Similar numbers of species of the same age were planted in each site. The tree species planted were: *A. tortilis, A. senegal. A, mellifera, Dobera glabra, Salvadora persica, Adenium obesum, Melia volkensii, Cordia sinesis,* and *Parkinsonia aculeata.* Four millimetres (4 mm) of rain fell immediately before planting but only 9 mm was received at the site in 6 months. Monitoring was subsequently undertaken to estimate the extent of regeneration.

Data collection

The heights and root collar diameters of all trees planted were taken at beginning of study, after 6 months and 2 years after establishment. Species counts were done for the two sites and also vegetation counts were made at the two sites following methods described by Muturi *et al*. (2014a).

Micro-catchment design

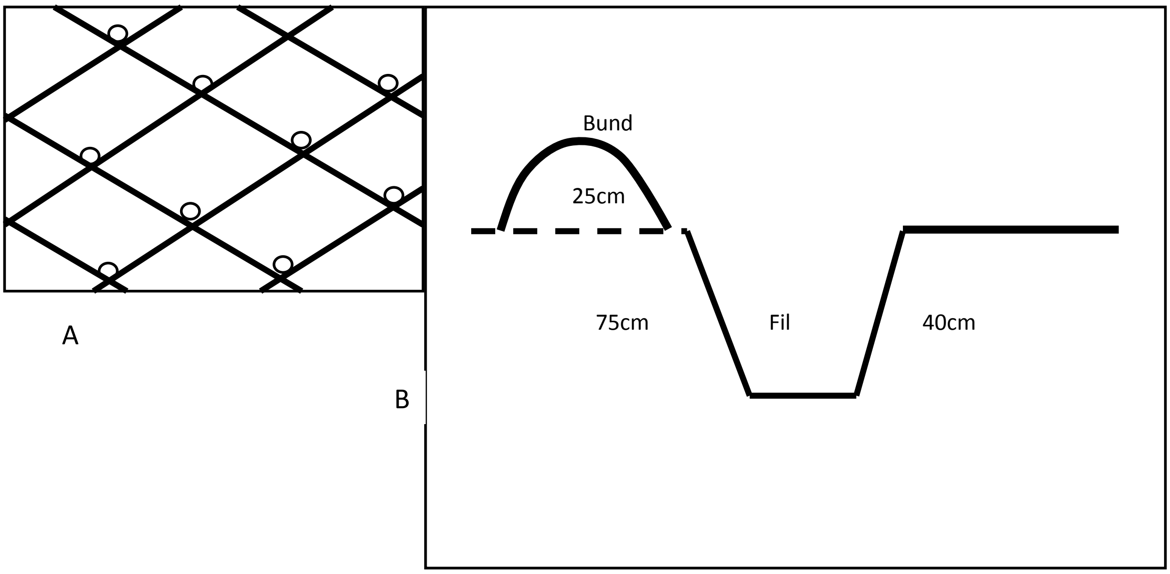

Figure 1. Micro-catchments in a plot (A) and a side view of bund and hole for trapping water in a micro-catchment (B)

Plate 1. Fenced plot (A) and non-fenced plot (B) showing species in a micro-catchment

Plate 2. Area with micro-catchment and abundance of vegetation

Data analysis

Data on tree height and root collar diameter was keyed in and summarized in R statistical software where means and percentages were generated and results illustrated in graphical charts. Differences were analysed with ANOVA and Post-hoc Tukey HSD.

Results

The boxplot (Figure 2) shows the median height of species planted in micro-catchments and outside micro-catchments. Tree species planted in the micro-catchments showed a median height of 67.5 cm while tree species planted outside micro-catchments showed a median height of 35 cm. Most trees in the micro-catchment had heights between 36 and 90 cm; and heights as low as 10 cm and as high as 115 cm. Most tree species outside the micro-catchment had heights of between 24 cm and 56 cm and height as low as 9 cm.

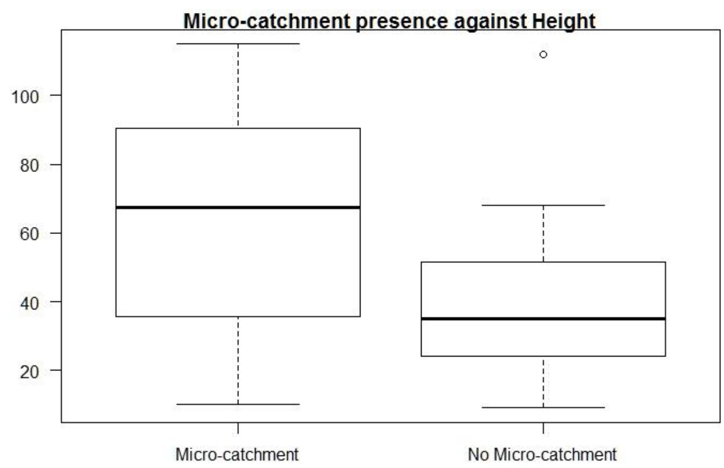

Figure 2. Boxplots showing tree species height comparison in the two sites

The boxplot results (Figure 3) show the median root collar diameter (RCD) of tree species planted inside the micro-catchment and outside micro-catchment. The median RCD of tree species inside the micro-catchment was 13.6 mm while the median RCD of tree species planted outside micro-catchment was 5.5 mm. Most trees in the micro-catchment had RCD between 10 mm and 18.1 mm; and RCD as low as 3.5 mm and as high as 21.5 mm. Most tree species outside the micro-catchment had RCD of between 5 mm and 7 mm; and RCD as low as 3.5 mm and as high as 8.2 mm.

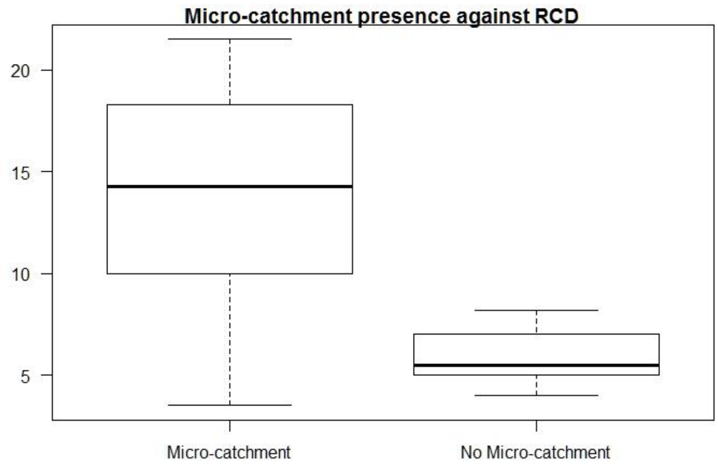

Figure 3. Boxplots showing tree species root collar diameter comparison in the two sites

The results (Figure 4) show that the trees planted in micro-catchments had significantly higher mean heights compared to the trees planted in the control site. *Acacia senegal, Acacia mellifera, Dobera glabra* and *Cordia sinensis* in the micro-catchments had a higher mean growth in height of 95, 66.5, 31 and 79.4 cm, respectively than those planted without micro-catchment at 6 months after establishment. *Adenium obesum, Melia volkensii* and *Parkinsonia aculeata* in the control site died out in the course of experiment hence no results were recorded 6 months later. In the control site, *Acacia senegal* and *Cordia sinensis* were taller than other species with heights of 84.5 cm and 57 cm respectively.

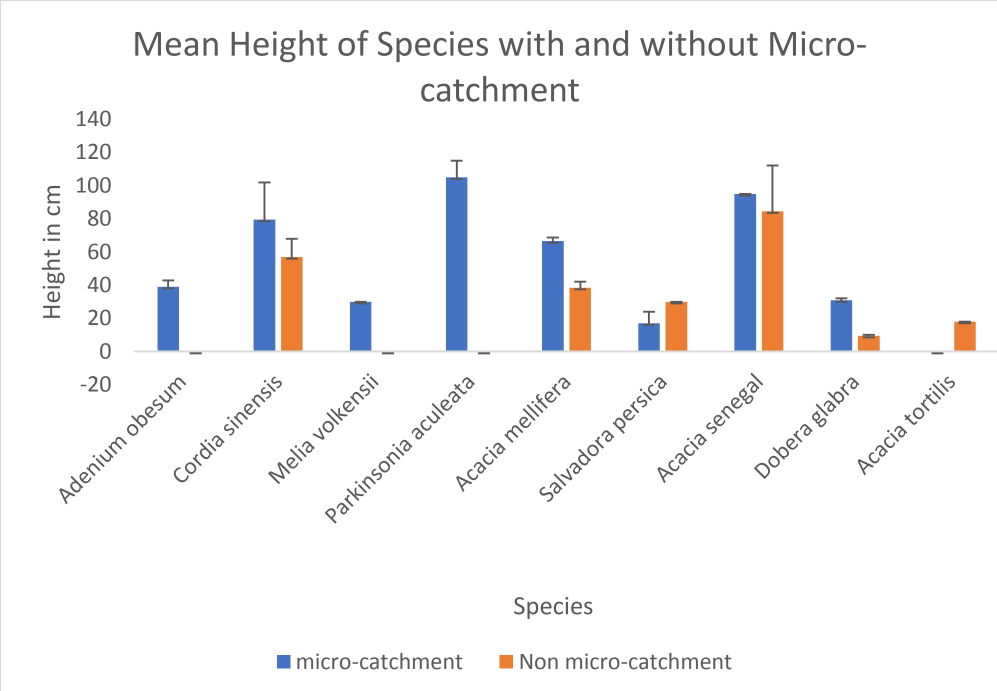

Figure 4. Individual species mean heights in the two sites after 6 months of establishment

The percentage increase in tree height of most species was directly proportional to increase in DBH. *Salvadora persica* had the highest percent increase in height and the lowest increase in DBH. The heights of *Adenium obesum*, *Cordia sinensis*, and *Parkinsonia aculeate* increased by over 50% in the period between 6months old and 2 years old. While the increase in DBH of Adenium obesum was slightly above 50%, the other species *S. persica*, *A. melifera*, *C. sinensis*, *A. senegal* and *P. aculeata* ranged between 7% and 32%. See Figures 5 and 6 .

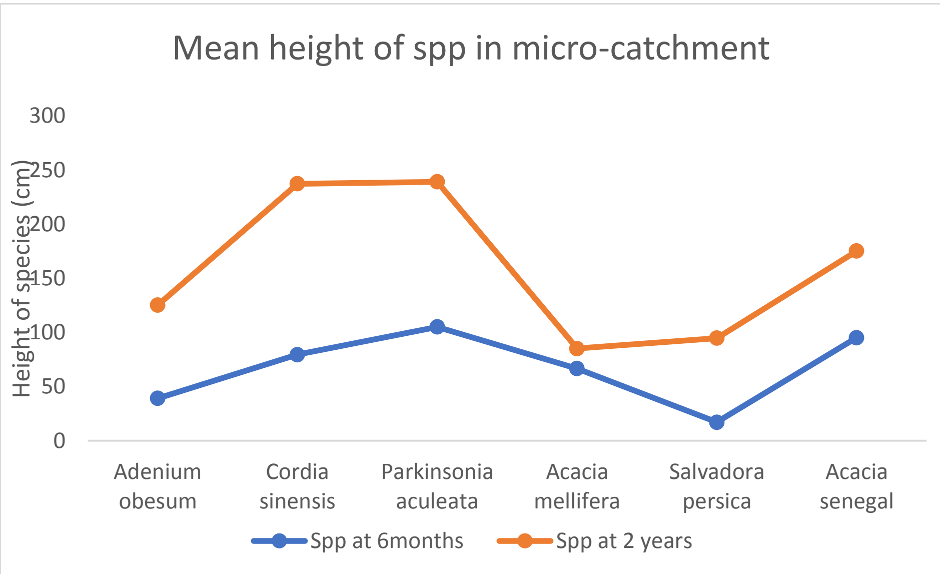

Figure 5. The percent increase in mean height and DBH of species in the site with micro-catchment between 6 months and 2 years of establishment.

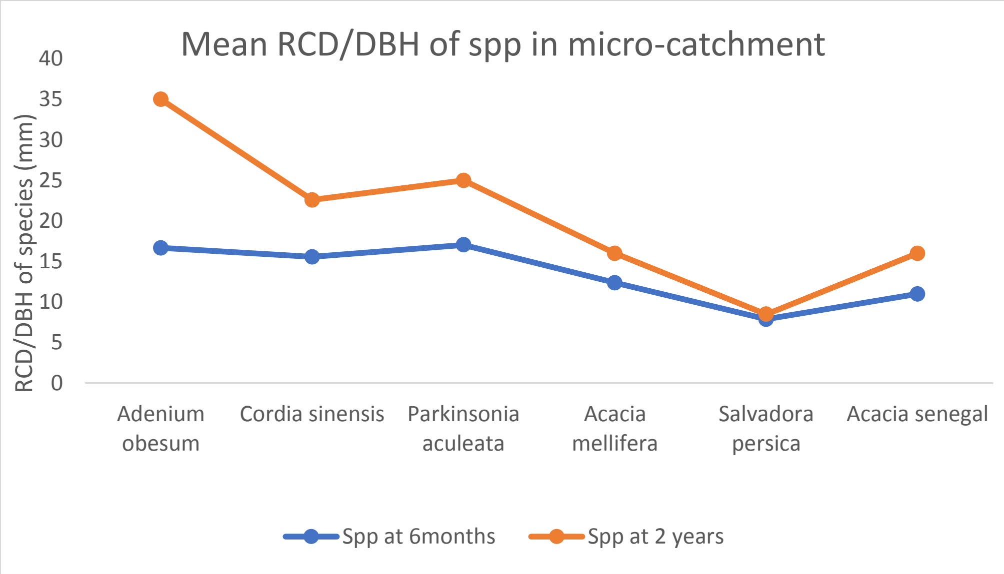

Figure 6. Comparison of mean height and DBH of species in micro-catchment at 6 months and 2 years old.

Table 1. Tree species counts in areas with and without micro-catchments 6 months after transplanting

Species	Micro-catchment	
	Yes	**No**
Acacia mellifera	4	2
Acacia senegal	1	2
Acacia tortilis	0	1
Balanites aegyptiaca	0	1
Cordia sinensis	18	2
Adenium obesum	4	0
Dobera glabra	2	2
Melia volkensii	1	0
Parkinsonia aculeata	2	0
Salvadora persica	4	1

The micro-catchment site had a higher species density compared to sites without micro-catchment. In the micro-catchment sites, *Cordia sinensis* had the highest density while *acacia Senegal* and *Melia volkensii* had the lowest density. *Melia volkensii*, *Adenium obesum* and *Parkinsonia aculeata* were present in the micro-catchment and absent in the site without micro-catchment.

Table 2. Herbaceous species density within quadrats in sites with and without micro-catchments

Treatment	**Species density/ m^2**	**Species counts /ha**
Micro-catchment	52	520,000
No micro-catchment	12	120,000

The herbaceous density was higher in sites with micro-catchments compared to sites without micro-catchments with 520,000 and 120,000 species per hectare. Sites without micro-catchment had only one herbaceous species (*Indigofera spinosa*).

Discussion

Effectiveness of micro-catchments in rangeland rehabilitation

The contrasting tree species height and survival in the site with and without micro-catchments demonstrate the effectiveness of micro-catchments in range rehabilitation. This technology can be adopted by the local community to improve tree cover and livelihoods. The absence of *Melia volkensii*, *Adenium obesum* and *Parkinsonia aculeata* in the control site was probably because of the low soil moisture and poor infiltration of run-off. This clearly illustrates the importance of water harvesting structures in areas with low and unpredictable rainfall because micro-catchments have higher water collection efficiency and retain water which could have been lost through run-off and make it available to trees long after the rains have stopped (Haruna, 2014). This technology can be upscaled in areas with annual rainfall of 200 to 750 mm. The position of planting the tree should also be determined according to characteristics of the tree species and the soil type (Muturi *et al.*, 2014b).

Species performance in arid environments

The vegetation data shed light on the influence of micro-catchment on tree growth and survival in the harsh environment of Turkana County. Tree survival in arid areas under such natural conditions is usually poor (Haruna, 2014). However, the use of micro-catchments proved to improve establishment of indigenous tree species despite the limited amount of rainfall accompanied by high daily temperatures. The survival rate of trees grown in micro-catchments was found to be high, hence the need to advocate for the use of micro-catchments to enhance water infiltration rate. The native plant species outperformed the exotic species in growth and survival. This is because the native species are well adapted to prevailing environmental conditions. The study also revealed poor long-term survival of exotic species which in the course of the experiment exhibited much stress and majority of them died especially in sites without micro-catchment.

Herbaceous density

The high density of herbaceous species in sites with micro-catchments show the importance of enclosing a rehabilitated area to allow vegetation to establish. High infiltration rate and low grazing pressure could be contributing factors to the high herbaceous species density. The presence of a single species in sites without micro-catchment (*indigofera spinosa*) was associated with high grazing pressure leading to suppression of herbaceous species as well as low water infiltration rate during rainy season.

Conclusion and recommendation

Rehabilitation of degraded ASAL areas is possible if effective measures and technologies are employed. The results from the study show that, the use of native species with proper water harvesting technologies can enhance tree survival and contribute to rehabilitation of degraded areas. The use of micro-catchments can be adopted by the local communities in Turkana to improve forest and ground cover, thus improving livestock production and environmental conservation. The correct choice of plant species and protection of young seedlings from domestic browsing species is important. Native species such as *Acacia senegal, Acacia mellifera, Cordia sinensis, Parkinsonia aculeate* are highly recommended for this region because of their fast growth, drought tolerance and properties of sustainability. It is necessary to encourage the local community to plant native plant species using micro-catchments as a rehabilitation strategy.

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Towards Rehabilitation of Degraded Woodlands in Charcoal Production Semi-Arid Areas of Embu County, Kenya

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Abstract

Unsustainable charcoal production is one of the key drivers of land degradation in the drylands of Kenya. To mitigate charcoal-driven degradation, the Government of Kenya enacted Charcoal Production Rules in 2009. Among the requirements is the formation of Charcoal Producer Associations (CPA) and a sustainable reforestation and conservation plan. However, there is limited local capacity in reforestation of the woodlands. This paper highlights preliminary findings of demonstrations on best-bet woodland rehabilitation technologies in two 1 ha plots in Mbeere North, Embu County. After sensitization meetings and trainings, seedlings of participatory selected indigenous charcoal producing trees were planted in 2014 and plots established for measurements of height, diameter growth and survival count for every 6 months in 3 years. Plots of 20 m x 5 m were systematically established within the demonstration sites for periodical assessment of natural regeneration. Mortality, height and relative growth rates were analyzed. Results have revealed significant differences in relative growth rates of planted seedlings (p<0.05). *Commiphora africana*, *Balanites aegyptica* and *Acacia tortilis* were the major tree species recruited naturally in both sites. Among the planted seedlings; *Acacia polyacantha*, *Tamarindus indica*, and *Balanites aegyptica* had over 50 % survival. The study has revealed tree species-site matching is crucial during woodland landscape restoration planning and implementation. The study recommends continued monitoring of the demo plots and uptake of introduced technologies among the CPA members and the local community in general.

Key words: Restoration, natural regeneration, charcoal, woodlands, Mbeere

Introduction

Tropical savannas and woodlands are among the most degraded and threatened ecosystems (MacFarlane *et al.* 2015).The drivers of woodland degradation can result from overuse of resources, climatic conditions such as increased drought frequency, urbanization and agricultural expansion (Waroux and Lambin, 2012). In Kenya, the settlements of nomadic pastoralists and migrants from high potential areas to marginal areas is increasing demand for firewood, charcoal, timber and encroachment of agriculture into forestland and woodlands, and consequently causing rapid deforestation and forest degradation. Particularly threatened are riverbanks, hilltop forests and bush lands. These areas are considered biodiversity hotspots and of high ecological importance due to the abundance of indigenous tree species, availability of medicinal plants, wildlife and non-wood forest products. The manifestation of this problem can lead to changes in the vegetation composition, structure and densities, decreasing the ability of the ecosystem to support livelihoods and economic development (Ndegwa *et al.*, 2016).

Unsustainable charcoal production has been confirmed by various studies as a key driver of woodland degradation (Chinduiyo and Gumbo, 2013); Ndegwa *et al.*, 2016; Sedano *et al.*, 2016; Kiruki *et al.*, 2017. Charcoal production is also a threat to biodiversity because it targets specific preferred species found in natural forests and woodlands, most of which are poorly managed, leading to unsustainable harvesting (Njenga *et al.*, 2013). In addition, clear-cutting or felling of desirable species for charcoal production is more prevalent in the drylands; with the preferred species mix and overall volume reduced, landscapes are often transformed from woodland to bush, and from bush to scrub. Studies by Mutimba and Barasa (2005) have shown that although firewood is also a major source of wood fuel for domestic use, it is normally harvested within the sustainable cycle of tree regeneration through selecting branches or already dead wood from farms or forests; it is thus a minor driver of forest degradation.

In Kenya, between 1.6 and 2.4 million tonnes of charcoal are consumed annually (Mutimba and Barasa 2005) with 87 % of this coming from private and communal woodlands in drylands. The consumption is likely to increase with urbanization and population growth, and this will consequently lead to increased negative impacts on sustainability of the woodland resources. The findings of Mutimba and Barasa (2005), caution that the absence of tree replanting practices will accelerate desertification and land degradation. In view of the contribution of charcoal production to the national economy, the government formulated a policy guideline for sustainable charcoal production. Among the requirements is the formation of Charcoal Producers Association (CPA) and a sustainable reforestation and conservation plan. However, there is limited local capacity in the reforestation of woodlands in the drylands of Kenya.

Since time immemorial, the vegetation resources in the drylands have been viewed as abundant and sustainable by the local communities and the approach has been pegged in conservation. Rehabilitation has not been given adequate attention until a few decades ago when the resources started to decline in an alarming rate. The concept of rehabilitation and restoration of the degraded forest and woodland landscapes have been given attention by both county and national governments through their development agendas such as in implementation of respective County Integrated Development Plans (CIDPs) and vision 2030 (GOK, 2007). Rehabilitation will support realization of the economic blue print goals of achieving ten percent forest cover of the country's surface area by 2030. Moreover, Kenya has committed to restore 5.1 million ha by 2030 through the international bidding Bonn challenge. The restoration technologies being introduced to the charcoal producers who are direct beneficiaries of the woodland products will play a big role in enhancing their capacity not only in supporting realization of the national goals but also providing local needs within their locality. The use of indigenous fast growing species that are adapted to the local climatic conditions are usually recommended in reforestation plans to meet ever increasing demand for wood fuel (Njenga *et al.*, 2013). These species require low levels of capital and management input and they respond significantly to very small amounts of water, which is a dominant condition in the drylands of Kenya. Rehabilitating degraded land by increasing the number of trees in the landscape is a key element for sustainable wood energy production and reduction of pressure on natural forests. Both highly productive plantations and agroforestry practices can contribute to the sustainable development of the wood-energy value chain, leading to a significant generation of supplementary revenue, especially for rural households. Area enclosures and assisted natural regeneration (ANR) are passive forms of restoration, which are relatively simple and low-cost to implement in rehabilitation of degraded woodlands. They aim at protecting rehabilitation sites from human and animal disturbances and enhancing natural regeneration; plant and animal diversity; vegetation biomass; and improving soil physical and chemical properties (Mengistu *et al.*, 2005; Yirdaw *et al.*, 2014). Therefore, this study was aimed at assessing demonstrations on best-bet woodland rehabilitation technologies in a semi-arid area of Kenya. Specifically, we assessed the growth performance of preferred charcoal producing tree species in terms of height, relative growth rate and total mortality in two sites managed by local charcoal producer groups. The study also assessed the potential of recruitment of natural regeneration in degraded areas in the two demonstration plots in Mbeere North, Embu County.

Materials and Methods

Description of the study site

The study was conducted in Mbeere North sub-county, Embu County. The sub-county has an area of 771.1 km^2 and is divided into four divisions namely; Kanyuambora, Mutitu, Evurore and Siakago. Population was estimated to be 99,587 in 2017 based on the projection of 2009 population census (CIDP, 2013). The climate is characterized by low unreliable rainfall, falling in two distinct seasons, one shorter and less reliable (March to May) and the other longer and more reliable (October to January). Mean annual temperatures range from 20 to 32 °C with low humidity (CIDP, 2013; Kamau, 2004). The area is classified as a medium to marginal land with the later forming the larger proportion on the sub-county. The soils in the district are largely sandy with those around the hills mostly rocky and not ideal for tillage.

The predominant agro-ecological zones range from semi-humid to semi-arid, apart from pockets of hills which have modified micro-climate. Kiang'ombe hill is the highest mountain within the sub-county and a major water catchment area. The hilltop is under threat from clearing for cultivation especially on steep slopes, wildfires and charcoal production. The other small hills within the sub-county have been sub-divided in to farms and are currently heavily degraded.

The source of livelihood is mainly derived from mixed farming and agro-pastoralism. Although cotton has been cultivated for commercial purposes, *Catha edulis* locally known as "muguka" is emerging as a cash crop in central areas of the sub-county. Firewood and charcoal are the main sources of domestic energy which is mainly sourced from farmers' private farms and county managed Kiang'ombe Hill forest. Commercial charcoal production is usually practiced in Saikago and Evurore divisions.

Establishment of demonstration plots

The demonstration plots were participatorily established in Kirie (Siakago Division) hereafter referred to as Demo1 and Evurore (Evurore Division) hereafter referred to as Demo 2 (Figure 1). The choice of the sites was deliberate since the local communities are actively involved with commercial charcoal production and there is existence of charcoal producer Associations (CPA). The two sites are about 5 km apart but with diverse differences in terms of vegetation and previous land use. The land use in Demo 1 had been a grazing area with few scattered trees mainly *Boscia coriacea, Acacia tortilis, Balanites aegyptiaca* and *Commiphora africana.* Demo 2 was under cultivation for maize and green grams with few scattered trees of *Terminalia brownii* and *Acacia nilotica*.

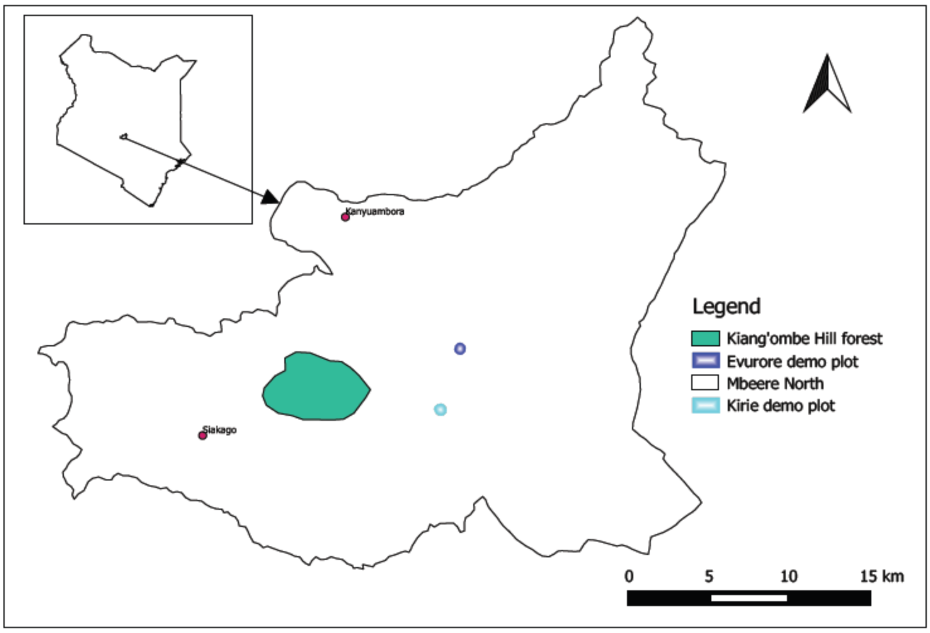

Figure 1. Location of Kirie and Evurore demo plot in Mbeere North

Charcoal Producer Association members were involved in woodland restoration through selection of the site and priority seedlings for planting in demo plots. After this exercise, and to enhance uptake and adoption of the rehabilitation technologies, roles were divided among the local community and the implementers. The CPA members mainly provided labour during fencing, planting and construction of soil and water conservation structures. This was followed by site selection, delineation of boundaries and fencing of the plots. The tree seedlings planted in Demo1 and Demo 2 are shown in Table (i). Each demo plot was divided into 3 blocks based on topographic factors. A plot consisting of 10 seedlings of each species was established, the seedlings were planted in 3 m x 3 m spacing. Each plot was replicated 3 times in each block. In addition, five nested plots of 20 m x 5 m were systematically established within the demonstration sites for periodic assessment of natural regeneration. Since the study area was heavily degraded, the extensive method of Barnet and Stolgren

(2003) was used. The main plot of 20 m x 5 m was used for the assessment of mature trees, saplings and regenerating seedlings.

Table 1. Tree species planted in demonstration plots in Mbeere North

Botanical name	Family	Demo 1	Demo 2
Acacia tortilis[0]	Mimosaceae	✔	✔
Acacia elatior	Mimosaceae	✔	✔
Acacia mellifera	Mimosaceae	✔	✔
Acacia Senegal[0]	Mimosaceae		✔
Acacia polyacantha	Mimosaceae	✔	✔
Balanitesaegyptica	Balanitaceae	✔	✔
Tamarindusindica	Caesalpinaceae	✔	✔
Terminalia brownii	Combretaceae	✔	✔
Delonix elata[0]	Fabaceae		✔

The sign (✔) shows the species planted in respective demo plots, the sign ([0]) shows seedling failed to establish in the first year, beating up was done in the second year but they have been excluded in this study.

Data Collection

Data on height and mortality rates we taken during establishment and after every 6 months for 3 years. Mortality was calculated using Equation 1(Sheil *et al.*, 1995)

$$M/100 = 1 - (N_1 / N_0)^{(1/t)} \quad \text{(Equation 1)}$$

Where M is mortality rate (percentage of seedlings per year), N_0 and N_1 is the number of seedlings alive at the beginning and end of the measurement, respectively, t is the number of years between measurements.

Relative growth rates (RGR) of the planted seedlings was determined using equation 2 (Hunt, 1982). The RGR is an index of the functional efficiency in plants that has a close relationship to species performance.

$$RGR = \ln(H_2 - H_1 / t_2 - t_1) \quad \text{(Equation 2)}$$

Where ln is natural logarithm, H_2 is height at final t_2 and H_1 is the height at time t_1. In all the plots, the seedling status was recorded as live, dead and the cause of death was participatorily evaluated.

In the natural regeneration plots, tree species, saplings and seedlings were identified and enumerated. This study reports on the emerging seedlings identified and their mean heights.

Data analysis

Statistical analyses were performed using One-way analysis of variance (ANOVA) procedures to test the growth and mortality data of the planted tree species. Since plots and blocks had different numbers of seedlings due to establishment failures, unbalanced regression was used to perform all the statistical analysis. Data collected for natural regeneration and from farms were evaluated using descriptive statistics.

Results

Growth performance and mortality in Demo1-Kirie

Mean tree heights were significantly different between the blocks ($p<0.001$). Among the specific trees, *Acacia polyacantha* and *Acacia eliator* showed the highest growth while *Acacia mellifera* and *Balanites aegyptica* recorded the lowest growth rate (Table (ii)). There was significant difference within the blocks in demo1 ($p< 0.05$) but there was no significant difference in mortality among the species ($p=0.08$). The highest mortality was recorded in *Acacia eliatior* (56 %) and *Acacia mellifera* (49 %). However, low mortality rates were recorded for *Terminalia brownii* (23 %) and *Acacia polyacantha* (28 %) (Figure 2).

Table 2. Mean height (± SE) and RGR of tree species planted at Demo1 after 3 years

Tree species	N	Height$_1$ (m)	Height$_2$ (m)	RGR (cmyr^{-1})
Acacia eliatior	53	0.41±0.012	1.51±0.017	4.347±0.234
Acacia mellifera	61	0.33±0.007	0.58±0.013	2.310±0.643
Acacia polyacantha	86	0.29±0.006	1.71±0.041	4.443±0.127
Balanites aegyptiaca	76	0.32±0.006	0.62±0.010	2.894±0.345
Tamarindus indica	70	0.33±0.008	1.09±0.009	4.168±0.348
Terminalia brownii	92	0.29±0.006	0.65±0.007	2.993±0.341

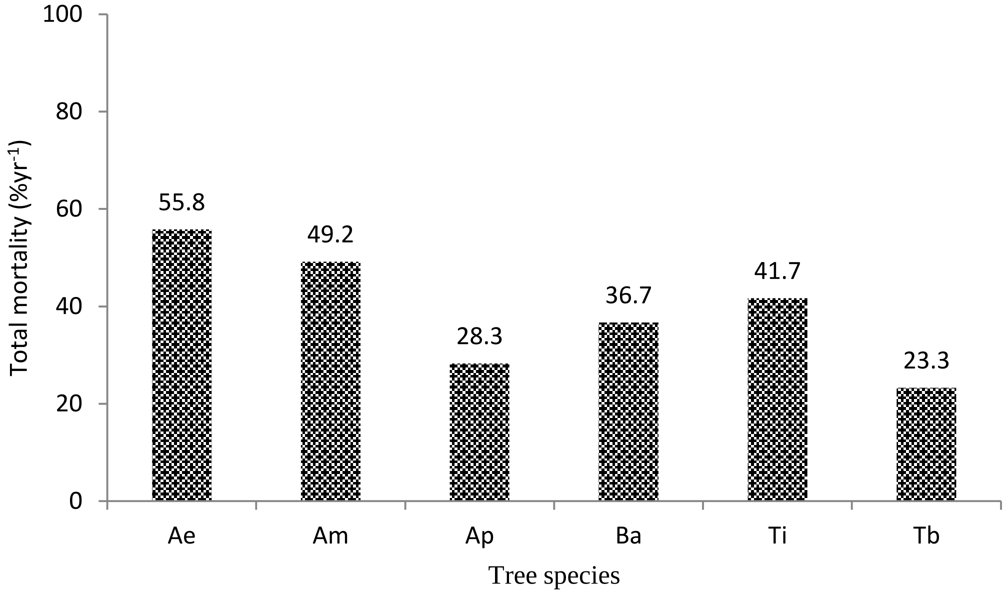

Figure 2. Total mortality (%) after 3 years of the tree species planted in demo 1. The species were; Ae-*Acacia eliatior*, Am-*Acacia mellifera*, Ap=*Acacia polyacantha*, Ba-*Balanites aegyptica*, Ti-*Tamarindus indica*, Tb-*Terminalia brownii*

Growth performance and mortality in Demo 2 - Evurore

There was no significant difference in mean tree heights between the blocks (p=0.902) but there was significant difference in mean heights among the tree species in the final measurement ($p < 0.001$). *Acacia polyacantha* and *Terminalia brownii* showed the highest growth while *Acacia mellifera* and *Tamarindus indica* recorded the lowest growth rate (Table 3). Although there was significant difference in mortality among the species ($p<0.05$), there was no significant difference in mortality among the blocks (p=0.789). The highest mortality was recorded in *Acacia mellifera* (22 %) and *Tamarindus indica* (22 %). However, low mortality rates were recorded in *Acacia eliatior* (13 %) and *Terminalia brownii* (23 %).

Table 3. Mean height (± SE) and RGR of tree species planted at Demo 2 after 3 years

Tree species	N	$Height_1$ (m)	$Height_2$ (m)	RGR ($cmyr^{-1}$)
Acacia eliatior	67	0.36±0.012	0.95±0.026	4.08±0.567
Acacia mellifera	50	0.27±0.008	0.80±0.032	2.98±0.387
Acacia polyacantha	54	0.32±0.013	2.10±0.216	4.59±0.237
Balanites aegyptiaca	62	0.25±0.007	0.98±0.186	4.15±0.145
Tamarindus indica	50	0.22±0.007	0.78±0.080	4.01±0.326
Terminalia brownii	63	0.23±0.006	0.97±0.163	4.16±0.325

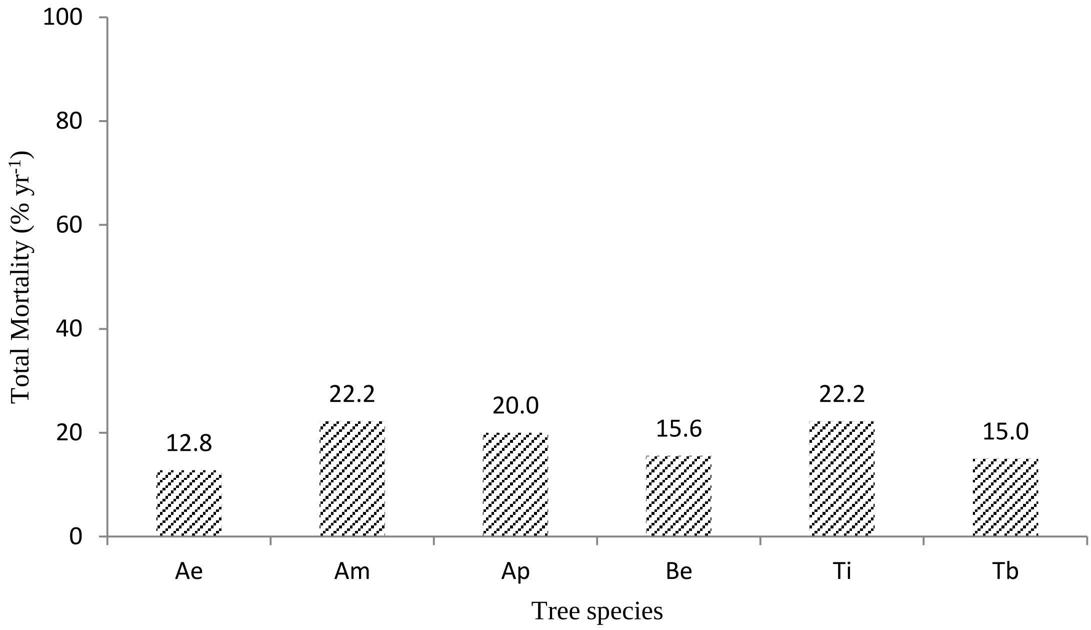

Figure 3. Total mortality (%) of the tree species planted in demo 2 after 3 years. The species were; Ae-*Acacia eliatior*, Am-*Acacia mellifera*, Ap=*Acacia polyacantha*, Ba-*Balanites aegyptica*, Ti-*Tamarindus indica*, Tb-*Terminalia brownii*

Seedling recruitment through natural regeneration

Natural regeneration recruitment in Demo 1 was higher than in demo 2 (Table 4). *Balanites aegyptiaca* (365 seedlings per hectare), *Commiphora africana (*273 seedlings ha^{-1}) and *Acacia tortilis* (167 seedlings ha^{-1}) had the highest density of seedlings in demo 1. *Acacia nilotica* and *Boscia coriacea* were only recruited in demo 1. *Acacia tortilis* was the only tree species with over 100 seedlings per ha recruited in demo 2. *Acacia hockii* had the least number of recruited seedlings in both sites. Most of the seedlings recruited were over 0.2 m in mean height. The highest mean height was recorded for *Terminalia prunoides* (0.48±0.082 m) although it was only found in demo 2 (Table 4)

Table 4. Density (seedlings ha^{-1}) and mean height (± SE) of recruited tree species in demo 1 and 2 after 3 years

Species	**Demo 1**		**Demo 2**	
	Density	**Mean height**	**Density**	**Mean height**
Acacia tortilis	167	0.41±0.023	107	0.37±0.023
Acacia nilotica	24	0.21±0.176	N/A	
Acacia hocki	15	0.37±0.076	3	0.34±0.031
Acacia senegal	81	0.39±0.094	17	0.17±0.067
Boscia coriacea	74	0.19±0.073	N/A	
Commiphora africana	273	0.35±0.074	55	0.26±0.037
Terminalia prunoides	N/A		17	0.48±0.082
Balanites aegyptiaca	365	0.27±0.120	23	0.32±0.091

N/A indicates the seedlings were not recruited in the respective demo

Discussions

The RGR recorded in this study is slightly higher than recorded in Northern Kenya of similar tree species of between 1.0 and 4.0 cm per year (Olukoye *et al.,* 2003). However, the study in Northen Kenya was for trees grown in saline soils. The studies of Joubert *et al.* (2017) in Namibia on the growth rate of *Acacia mellifera* for over 35 years compares well with the present study. However, competition and the previous land use are important issues which determine the growth rate of tree species. The high growth performance of *Acacia polyacantha* in both demos is in agreement with other studies (Mulizanne *et al.,* 2005). However, it should also be recognized that RGR and mortality rates of indigenous tree species are not the only relevant information for selecting species for rehabilitation and restoration in charcoal harvesting areas. It is likely, that some species considered relatively poor performers on these criteria, may be included in restoration plans because of their importance as restoration facilitators acting, for example, to provide shade, to develop soils, to develop structural complexity or to attract seed dispersers. For example, *Acacia mellifera* is well known to be very good for live fences and honey forage. Recognizing that the tree species were growing under adverse conditions, a mortality rate of below 25 % in demo 2 indicates that the trees performed exceptionally well. This demonstrates the importance of land preparation before tree planting.

The demo plot which was previously under grazing had higher naturally recruitment seedlings compared to previously cultivated demo plot. This is a clear indication of the role livestock play in dispersal and breaking dormancy of tree seeds. Recruitment of seedlings through natural regeneration indicated *Balanites aegyptica*, *Commiphora africana* and *Acacia tortilis* can be recruited successfully in degraded areas. Although *C. africana* has low charcoal quality it is ideal for restoration of degraded areas

Conclusions

The indigenous species used in this study showed considerable variation in RGR and mortality rates. The preliminary results suggest that *Acacia polyacantha* and *Terminalia brownii* perform well in terms of early survival and growth of seedlings and may be useful species in projects that aim to restore degraded woodlands especially in charcoal production areas. It is recommended that restoration projects, particularly large scale ones, should utilize growth performance while selecting candidate tree species. Tree species-site matching is crucial during woodland landscape restoration planning and implementation. The study recommends continuous assessment to elucidate more findings as the tree species continue to grow. The study also recommends continued monitoring of demo plots and uptake of introduced technologies.

Acknowledgement

The authors acknowledge the financial support from GEF/UNDP through Sustainable Land Management Project and Government of Kenya. The Director, KEFRI and the Regional Director, Central Highlands Eco-region Research Programme (Muguga) are highly appreciated for facilitating implementation of the project activities. We are also grateful for logistic support received from other partners namely; Kenya Forest Service and State

Department of Livestock Development. Lastly, special gratitude goes to the local communities, who willingly collaborated with project implementers.

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THEME 3: SOCIO-ECONOMICS, POLICY AND GOVERNANCE (SPG)

Meeting with community members

Timber trade

On-Farm Tree Growing Opportunities and Constraints in Murang'a County, Kenya

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Abstract
Careful and efficient collection of information on agroforestry practices at different agro-ecological zones has a great contribution to promote or to improve important agroforestry practices. This survey was conducted with the objective of identifying major reasons for on-farm tree planting, tree species preferred and prioritizing major constraints to tree planting in Murang'a County, Kenya. The survey was done on selected farmer households in Murang'a North, South and East sub-counties. The data was collected using a pre-tested questionnaire and analyzed with SPSS software. Among tree species most popular in all sub-counties include *G. robusta, C. eminii, P. americana* and *C. macrostachyus*. These species are valued by farmers for their products including fuelwood, fruits, timber, fencing and ornamental. About 30 tree uses were recorded. About 81 % of respondents face various constraints in tree growing such as drought, pest attack, theft, high cost of seedlings, poor soils animal browsing and trees competition with crops. Despite the constraints, 93 % of respondents have plans to plant more trees in future, with preferred species being *G. robusta* , *P. americana* , *M. indica* and *Eucalyptus spp* . These species provide income, timber, fuelwood, and fruits. Farmers also prefer tree species that don't compete with agricultural crops and grow fast. Most of the farmers with future tree planting plans preferred boundaries planting. The study findings can guide tree planting in Muranga county and similar areas.

Key words: Opportunities, constraints, tree species, Muranga, agroforestry

Introduction
High population densities, intensive cultivation, fragmentation of family land and rapid decrease in land available for farming are some of the major causes of soil erosion, soil nutrient depletion, and wood fuel and timber shortages in the highland areas of Kenya (Ngugi and Brabley, 1986). It is encouraging that farmers in Kenya, in response to loss of forest cover, have been successful in cultivating and managing trees in and around their farms. Trees on farm or agroforestry systems and practices come in many forms including; improved fallows, Taungya or Shamba system, home gardens, among others. It is upon the realization of the importance of trees in Kenya's socio-economic and environmental development that the constitution of Kenya mandates that the State increase tree cover to 10 % of its total land area, the minimum recommended for ecological sustainability. Farm Forestry Rules (2009) require farmers to establish and maintain farm forestry on at least ten percent of every agricultural land holding. The promotion of farm forestry in most parts of Kenya's central highlands has, however, resulted to the farmers' adoption of a few tree

species. *Grevillea robusta* has been well adopted such that it forms a near monoculture in central Kenya highlands, particularly in Kirinyaga District where it was found to be grown on about 96 % of farms (Tyndall, 1996). Such a near monoculture agroforestry system is, however, very delicate. According to Njuguna, (2011), the species is under threat from a widespread canker and dieback disease and a host to over forty fungal species, some of which cause serious diseases of other woody species as well as agricultural species. Diversification of tree species composition is therefore important and can lead to enhancements of stability and productivity of ecosystems (Cottingham *et al.* 2001).

Careful and efficient collection of information on agroforestry practices has a great contribution either to promote or to improve important agroforestry practices. Thus the survey was conducted with the objective of describing and understanding various agroforestry practices, identifying and characterizing major tree species, identifying reasons for tree growing, what tree species farmers most want to plant in their farms and also identifying and prioritizing major constraints related to tree planting.

Methodology

Study site

Murang'a County is one of the five counties in central region of the republic of Kenya. It covers an area of 2,558 square kilometers and borders Nyandarua County to the west, Embu County to the east, Nyeri County to the north, Kiambu County to the south and Kirinyaga County to the north east (Figure 1). The county is divided into six agro ecological zones. The agro ecological zone one consists of the highest potential zones where forestry, tea and tourism industry form the most important economic activities. Agro-ecological zones two and three are the lowlands east of Aberdares and are generally suitable for both coffee and dairy farming. The flatter area of Makuyu division of Maragwa constituency is characterized by arid and semi-arid conditions. This forms the agro ecological zones 4, 5, and 6. In these zones coffee and pineapple plantations thrive by irrigation (www.murang'a county.go.ke).

Figure 1. Muranga County (Courtesy: Tourists map Kenya Limited)

Three sub-counties of the county were selected for the study. They comprised of Murang'a north representing the upper elevations or the tea zone, Murang'a east representing mid altitude elevation or coffee zone and finally Murang'a south representing the lower altitude elevation or the sisal/ pineapple zone (Table 1).

Table 1. A summary of households representation status per elevation class in the study areas

Sub county	**Households frequency (%) per altitude range (m)**				**Total**
	2201-2900	1801-2200	1281-1800	700-1280	
Muranga north	11 (22)	33 (66)	6 (12)	0 (0)	50 (100)
Muranga south	0 (0)	0 (0)	47 (94)	3 (6)	50 (100)
Muranga east	0 (0)	1 (2)	39 (96)	1 (2)	41 (100)

Elevation categories (Jaetzold and Schidt (1983))

> 2900 m = Afro-alpine highland
2201-2900 = Upper highland
1801-2200 = Lower highland
1281-1800 = Upper midland
700-1280 = Lower midland
< 700 = Inland lowland

Most of the households surveyed in Muranga north lies in the upper highland category while majority of the studied farms in Muranga south and east are in the upper midlands.

Sampling design

The survey was done on selected farmer households per sub-county. Selection was purposively framed so as to represent various heterogeneity features especially land use systems and altitudinal elevation, of each sub-county, constituency and ward levels. The upper altitudinal or tea zone was represented by Murang'a north sub-county. Two constituencies, Mathioya and Kangema, represented this zone while the selected locations include Gakuyu, Githiga, Ichichi, Kaero, Kanyenyaini, Kiriti, Kiru, Kiruri, Mioro, Njumbi, Nyakianga and Rwathia. The coffee or mid-altitude zone was represented by Kiharu constituency in Murang'a east sub-county. Several locations that were a true representation of coffee zone were chosen as Njoguini, Gikandu, Gakandu, Wangu, Gaturi, Kiria, Mugoiri, Mushungusha, Mbiri, Nyakihae, Gakuyu, Kigetuine, Wethaga and Kahuhia. Murang'a south as a sub-county is composed of Makuyu and Maragwa divisions. Maragwa's chosen locations included Nginda and Ichagaki while in Makuyu division the locations selected included Kambiti, Makuyu, Kimoroni, Wempa, Kirimiri, Sabasaba and Kamahuha. Simple random sampling was finally at village level to select households that were subjected to data collection. Working with a confidence level of 95 % and a confidence interval of 5 (margin error of 0.05), conditions widely accepted for a social science survey, and a household population of 135,244, a total of 141 households were included in the study (www.surveysystem.com/sscal.htm).

The data was collected using a pre-tested questionnaire. Several tools were used in the survey during data collection. They include a GPS for mapping the sampled farms, a running tape measure for measuring plots and tree crown diameter, a dbh tape measure for measuring tree diameter, a counter for counting or enumerating the trees, camera, questionnaires for recording the information, note book, pencil, eraser, sharpener and a folder.

Data analysis and presentation

A statistical package for social sciences (SPSS) template was created for the collected data to be coded and entered. It was then cleaned and subjected to various analyses. The information was presented as frequency tables and bar graphs.

Results and discussions

Tree growing history - general status of trees growing upon acquisition of land

In the sampled farmers, majority of their farms had trees already by the time of acquisition, with Muranga north and east leading. Most of the trees found in the farms were indigenous in all the sub-counties, with Muranga south leading with 83 % (Table 2).

Table 2. Status of trees growing upon acquisition of land

Sub county	Presence of trees on farm upon land acquisition by households (%)		Type of trees initially present on farm by households (%)	
	Trees present	**Trees absent**	**Exotic**	**Indigenous**
Muranga north	66	34	41	59
Muranga south	60	40	17	83
Muranga east	66	34	26	74
Total	64	36	29	71

Changes in initial tree species composition and reasons

All the respondents in both Muranga north and south have changed their initial tree species composition. In Muranga east, about 98 % have changed their species composition while only 2 % have not changed. The most significant change is an increase in exotic trees (58 %) of all the respondents and a decrease in indigenous trees (27 %) (Table 3).

Table 3. Kind of change of tree composition on farms

Sub county	Kind of change of tree composition by respondents (%)					
	Increased indigenous trees	Decreased indigenous trees	Increased exotic trees	Decreased exotic trees	Increased both	Decreased both
Muranga north	4	26	54	6	6	4
Muranga south	14	26	58	2	0	0
Muranga east	2	32	66	0	0	0
Total (Average)	7	27	58	3	2	1

Reasons for the tree composition changes

The main reasons for the tree composition changes include growing tree species with capacity to provide timber/ poles (28 %) and fuel (26 %) and also to give way for agriculture or house construction (14 %), among other reasons (Table 4).

Table 4. Reasons for tree composition changes

Sub county	Reasons for tree composition changes by respondents (%)								
	Fuel	Income	Fast growth	Shade	Wind break	Environ mental conserva tion	Timber/ poles	Fruits	Agricult ure/ homestea d
Muranga north	34	4	2	2	2	6	22	4	22
Muranga south	12	8	2	4	2	8	42	4	14
Muranga east	32	22	2	2	5	2	19	5	5
Total	26	11	2	3	3	5	28	4	14

Elsewhere, the type of seedlings raised depended mainly on growth characteristics and end uses. For example, *Eucalyptus saligna, Cupressus lusitanica and Grevillea robusta* are fast growing species and were targeted for fuelwood and timber (Ogweno *et al.,* 2001). Furthermore, seeds from these species are cheap and readily available through local collection. Farmers in Kipkaren catchment had varied preferences for different tree species as discussed by Imo *et al*., (2001). The most preferred indigenous trees were *Prunus africana* (70 – 91 % of the farmers), *Zizygium quineense* (60 to 80 %), *Erythrina tomentosa* (50 to 70 %) and *Croton macrostychus* (60 to 75 %), and had been retained in farmlands for timber, construction poles and firewood.

Major tree species present in Muranga County

The major 10 tree species in the three studied sub-counties of Muranga are summarized in the Table 5. *Grevillea robusta* was ranked highest in both Muranga east and south, being present in all the farms visited, while Eucalyptus was the most grown tree species in Muranga north.

Table 5. Major tree species in Muranga County

	Muranga east		**Muranga north**		**Muranga south**	
Rank	**Tree species**	**H/holds (%)**	**Tree species**	**H/holds (%)**	**Tree species**	**H/holds (%)**
1	*Grevillea robusta*	100	Eucalyptus spp	92	*Grevillea robusta*	100
2	*Mangifera indica*	95	*Persea americana*	92	*Mangifera indica*	100
3	*Bridelia micrantha*	90	*Grevillea robusta*	80	*Persea americana*	80
4	*Persea americana*	90	*Eriobotrya japonica*	76	*Croton macrostachyus*	70
5	*Croton macrostachyus*	87	*Acacia mearnsii*	74	*Bridelia micrantha*	68
6	*Commiphora eminii*	83	*Cyphomandra betacea*	74	*Carica papaya*	66
7	*Croton megalocarpus*	78	*Cupressus lusitanica*	62	*Psidium guajava*	66
8	*Psidium guajava*	75	*Croton macrostachyus*	60	*Commiphora eminii*	54
9	*Carica papaya*	68	*Croton megalocarpus*	48	*Cassia spectabilis*	50
10	*Markhamia lutea*	68	*Commiphora eminii*	46	*Markhamia lutea*	48

Among tree species present and ranked among the 10 most popular in all sub-counties include *G. robusta, C. eminii, P. americana* and *C. macrostachyus*. These are the species that are valued by most farmers and can grow well in high, mid and relatively lower altitudes. Another similarity observed in both Murang'a east and south, was occurrence of *Mangifera indica* as the second most popular tree species and not appearing amongst top ten tree species in Murang'a north. Other species present in both M. north and M. east but absent in M. north include *B. micrantha, P. guajava, C. papaya* and *M. lutea.* Some species were popular in specific locations such as *Eucalyptus spp, E. japonica, C. betacea, C. lusitanica* and *A. mearnsii* for M. north and *C. spectabilis* for M. south. Muranga east had the highest number of tree species (94) while both Muranga north and south had 84 tree species (Appendix I). In total, 134 tree species were identified in the three Muranga sub-counties. Most of the species appeared in more than one sub-county. There were, however, some species that were exclusively found in a particular sub-county, probably dictated by their ecological growth requirements among other factors. *Juniperus procera*, *Macaranga kilimandschariensis, Araucaria caninghamii*, *Araucaria heterophylla*, *Cussonia spicata* and *Maesa lanceolata* were exclusively recorded in M. north. Those species that were only found in M. east include; *Artocarpus heterophyllus*, *Celtis africana*, *Clausena anisata*, *Ficus lutea*, *Malus domestica, Margaritaria dioscoidea*, *Schrebera alata*, *Tipuana tipu*, *Trichilia emetica*, *Trimeria grandifolia* and *Milletia dura*. The species specific to M. south include; *Toddalia asiatica, Trema orientalis, Grewia bicola, Fraxinus pennsylvanica* and *Ficus benjamina*. Elsewhere, *Grevillia robusta* is considered by farmers in the highlands of East Africa to be an outstanding agroforestry tree. It is thought to be deep rooted and to possess few lateral roots, which suggests good potential for below-ground complementarity (Lott *et al*., 1996; Howard *et al*., 1997).

Tree size distribution

The diameter of trees on the studied farms indicated that trees of smaller diameter were generally more than those of bigger diameter classes, as shown in the Figure 2.

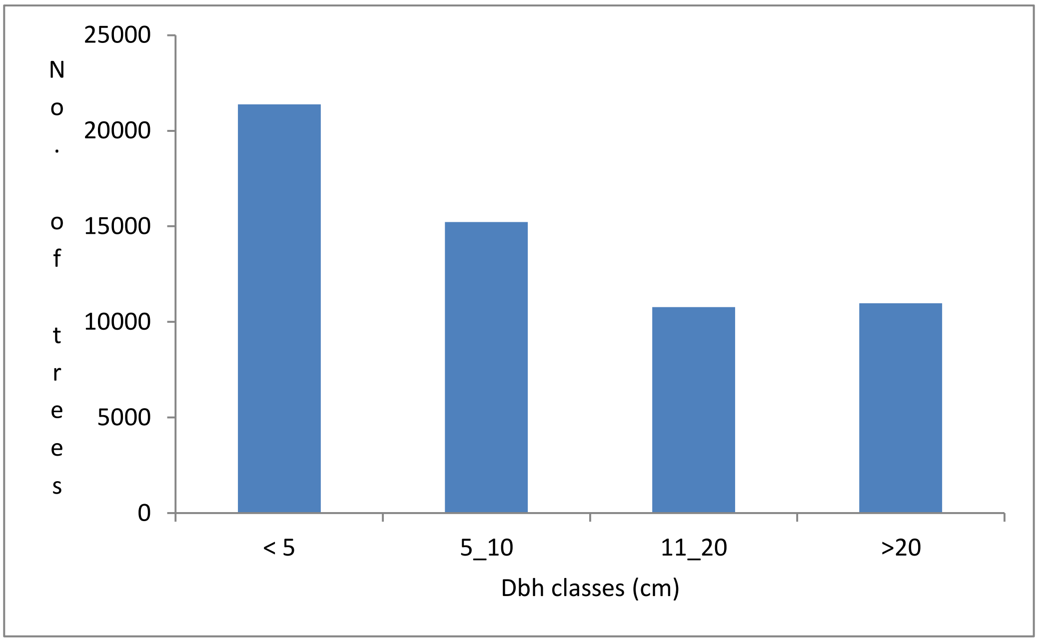

Figure 2. Tree size distribution

This is a desired pattern for any tree growing initiative since it shows that there is a prospective continuous provision of tree products in future. This is due to the presence of many young trees as compared to the older ones. Size distributions are considered an important indicator of population dynamics. A reversed J-shaped size distribution has been regarded as a proxy of population growth or dynamic equilibrium while a unimodal distribution, with comparatively fewer juveniles relative to adults, has been taken as evidence of population decline (Deb and Sundriyal, 2008).

Tree density and configuration in Muranga County

The total land size of the studied households was about 329.5 acres. The total number of trees counted was 58344. Therefore, the tree density (number of trees per acre) for the study area was 177.1411 trees per acre. There were several locations where farmers preferred to plant or nature their trees in their farms as outlined in the Table 6. The most preferred niche of trees on farms was when scattered irregularly and growing together with agricultural crops.

Table 6. Trees configuration in the farms

Trees on farm location	Frequency (%)
Scattered on-farm	38.1
On boundaries	26.5
Home compound	17.6
Woodlot	8.4
Contours/ terraces/ conservation structures	3.7
Hedgerows	3.4
Raparian	2.3

Scattered trees on croplands may involve planting of new trees or it may depend on careful management of selected seedlings established on site through natural regeneration (Rocheleau *et al*., 1988). Apparently, a significant number of farmers disliked trees in croplands due to their shading effects on the crops. But potential benefits of trees on farms have also been proven in Southern Africa like Zambia, Malawi and Zimbabwe where the intervention has been adopted (Sileshi *et al*., 2009). Thus, proper species selection for croplands, their arrangement and management would help make the practice more appealing hence encourage tree domestication.

Some farmers had planted trees in woodlots (i.e. a section of the farm is set aside exclusively for tree growing (Tejwani, 1987) mainly of exotic species such as *G. robusta, C. lusitanica* and *E. saligna*. These woodlots were managed mainly for poles, timber and fuel wood. Boundary planting (i.e. tree growing a long farm boundaries or demarcation within farms (Tejwani, 1987) was also practiced by many farmers in the study area.

Major tree uses

Farmers will plant trees due to perceived benefits out of the planted trees. The major 10 uses of the trees in the studied sub-counties include fuelwood, fruits, timber among others as summarized in the Table 7.

Table 7. Major tree uses of Muranga County

Tree use	Frequency (%)	Tree use	Frequency (%)
Fuelwood	32.41	Shade	2.8
Fruits	28.71	Fodder	2.66
Timber	9.93	Conservation	2.53
Fencing	5.32	Medicine	2.12
Ornamental	3.52	Income	2.03

Tree planting by farmers in Muranga County has been enhanced with the involvement of tea processing industries in establishing tree nurseries and supplying tree seedlings to farmers for planting. These industries buy mature trees from farmers who earn incomes while the industries get a source of wood fuel for their production (Muranga County, 2014). Farmers have also been planting fruit trees like Avocadoes, Mangoes, Pawpaws, Macadamia and Oranges for commercial and for nutrition purposes. There are Mango and Avocado processing factories in the county (Muranga County, 2014).

Other reported uses in order of their importance include charcoal, stakes, boundary marking, soil improvement, tools handles, ripening bananas, local brew, hanging beehives, tooth brushes, edible leaves, windbreaks, gum resins and oils, carving, basket making, insects and snakes repelling, pestle and mortar, making wheels and cultural / religious values. In total, 34 uses were reported. The reported uses are in agreement with Wickens (1980) who also illustrated that in the self-contained, low-economy peasant communities such as most part of Muranga county, the main role of multipurpose trees apart from their values as fodder is for the provision of food, medicine, fuel, timber, fiber, pollen, nectar, dyes, gums, waxes, resins and also play a very important role as wind-breaks, in providing shade and protection against heat and cold and in reducing erosion. Trees also control the water table, sequester carbon and mitigate floods (Sileshi *et al*., 2007), and hence climate change. A study by Santos-Martin *et al*, (2011), showed that access to markets has a positive influence on tree-planting activities, suggesting that improvements to rural infrastructure, including constructing or upgrading roads, encourages more intensive production of agricultural and tree crops.

The land ownership

Almost all the respondents in the study areas have their own land. Majority of land owners have title deeds and ownership is majorly on individual basis (Table 8). Very few respondents were not sure whether the land they occupy have a title deed or not. Acquisition of land is a prerequisite in any tree planting activity since it is the resource upon which they grow on. This is an impetus to tree planting since individual farmers have freedom of choice and can make quick decisions on the type of trees to be planted in their own farms. They could also manage their trees as they wish for their desired products.

Table 8. Land ownership and tenure status of farmers in Muranga county

Land ownership status		**Land tenure status**		**Possession of title deed**	
Status	Frequency (%)	Status	Frequency (%)	Status	Frequency (%)
Own land	99	Individual	80	Have title	74
Don't own	1	Family	20	Don't have	24

The study's findings are in agreement with. Muranga County, (2014) which reported the incidences of landlessness to be 0.2 % while the farmers with title deeds were 65 % and those without as 35 %. The land ownership could have significant influence in tree growing. In Phillipines, for example, Santos-Martin *et al*, (2011), found that the total area and number of parcels managed - and tenure security stand out as the main factors that affect farmers' decisions to plant native timber trees. It should also be noted that as tree planting is regarded as a mark of ownership right, customary tenure does not allow non-owners to plant trees, which is an important constraint for introduction of agroforestry systems (Neef, 2001).

Land size distribution

Most of the farmers in Muranga north (66 %), Muranga south (82 %) and Muranga east (58 %) have land sizes less or equal to 2.0 acres (Table 9). This implies that majority of farmers in Muranga county are small scale farmers.

Table 9. Land size classes in Muranga county

	Land size classes (in acres) frequencies (%)					
Sub-county	0-2.0	2.1-4.0	4.1-6.0	6.1-8.0	8.1-10.0	> 10.0
Muranga north	66	16	14	4	0	0
Muranga south	82	10	2	0	4	2
Muranga east	58	29	7	2	2	0
Total	68	17	7	2	2	1

According to Muranga County (2014), the average farm size for most of the county's households is 1.4 acres. Small scale farmers are, in most cases, known to have more trees per acre than their counterparts with large pieces of land. However, a study done in the coffee belts around Mt. Kenya concluded that tree abundance was generally low among smallholder farmers and suggested the need for increased tree abundance in order to support higher nutrient requirements (ICRAF, 2010).

Land gradient and soil conservation status for Muranga County

Most land in both Muranga north (68 %) and east (66 %) is slightly sloping while vast (70 %) of land in Muranga south is generally flat (Table 10). The GPS co-ordinates also classified most of Muranga north farms being upper and lower highland (Table 1). Although most farms in both Muranga east and south were in upper midlands, some farms in M. east were in lower highland while M. south had more farmers being located in the lower midlands altitudes. The land gradient and altitude dictates the type of crops grown per region and also the need and type of soil conservation measures.

Table 10. Land gradient and soil conservation status for Muranga County

Subcounty	Land gradient of farms (%)			Soil conservation presence (%)	
	Flat	Slightly sloppy	Very sloppy	Present	Absent
Muranga north	2	68	30	68	32
Muranga south	70	30	0	86	14
Muranga east	7	66	27	98	2
Total	26	55	19	83	17

Most of respondents who did not have any soil conservation measure (83 %) either had their land being flat or in case of those in sloppy areas had tea as the crop covering their farms. Tea is a good cover crop and mostly with a lot of mulch from periodic prunings. The rest of the respondents either had plans to undertake the conservation measures or had an opinion that they had small pieces of land and therefore did not see the reason to conserve it.

Type of soil conservation practices present

The most common type of soil conservation practiced in all the areas is the use of terraces (Table 11). The nappier grass was also planted alongside the terraces. Together with controlling soil erosion, the nappier grass also provide fodder for livestock.

Table 11. Type of soil conservation in Muranga county

Sub county	Type of soil conservation (%)				
	Terraces	Nappier grass	Trees	Contour plowing	Riparian reserve
Muranga north	80	14	3	0	3
Muranga south	81	19	0	0	0
Muranga east	80	17	0	3	0
Total	80	17	1	1	1

The potential for flood events in sloppy areas is increased by agricultural management practices and climate change. Construction of soil conservation structures in Muranga County is evident. Planting trees and hedgerows can significantly increase water infiltration rate into soil and storage. This reduces the potential for surface runoff and overland flow, which is key factor in reducing flood peaks (https://businesswales.gov.wales/farmingconnect/sites/farming/files/). Tree planting in farms has helped in preventing soil erosion. Trees also hold the soils firmly on the ground and act as wind breakers and increase soil fertility through litter fall from leaves which later form humus. The soil conservation structures namely; retention ditches, grass strips, trash lines and *fanya juu* are also practiced across the county (Muranga County, 2014). Young, (1997)

The source of tree planting material

About 58 % of responded cases revealed that the trees were planted while 42 % were not planted but rather retained and natured. Of the planted lot, the majority (48 %) were from the private tree nurseries, 21 % from wildings, 14 % from own tree nurseries and 12 % were from cuttings (Table 12). Other sources include government tree nurseries, group tree nurseries, friends/ neighbours tree nurseries and school tree nurseries.

Table 12. Sources of trees planting material

Source of trees planting material	Frequency (%)
Private tree nursery	48.3
Wildings	21.4
Own nursery	14.7
Cuttings	12.4
Government nursery	1.7
Group nursery	1.1
Friend/ neighbour	0.3
School	0.1

Elsewhere, in tobacco growing areas in Kenya (Eastern Western and Nyanza regions), the major sources of tree seedlings include the British American Tobacco sponsored tree nurseries, privately owned tree nurseries, own and neighbor/ friend's tree nurseries in that order of importance (KEFRI, 2017). This indicates the importance of private and own tree nurseries in provision of seedlings and the need to improve on other sources.

Tree planting constraints

About 81 % of respondents disclosed that they face various challenges when growing trees while 19 % do not face any challenge. The various challenges faced by the farmers and their respective frequencies are given in the Table 13.

Table 13. Muranga county tree planting constraints

Constrains	Frequency (%)
Drought	39
Pest attacks	24.9
Theft and destruction of trees	8.8
Seedlings expensive	8.3
Soil infertility	4.7
Animals browsing	3.5
Competition with crops	1.8
Lack of adequate land\ no tenure	1.8
Lack of labour	1.8
Dropping leaves on tea	1.2
Loss of tree value	0.6
Flooding	0.6
Lack of nursery materials	0.6
Bad policies, need for permission to harvest trees	0.6
Tree nurseries are far away	0.6
Poor planting method	0.6
Trees damaging structures eg buildings	0.6

The most prominent constraints include drought (39 %), pest and disease attack (24.9 %), theft and destruction of trees and the cost of buying seedlings being high. The problem associated with seed procurement is especially common with certain species, such as *Grevillea robusta*, *Hakea saligna, Olea africana* and *Terminalia mentalis*. Thus, promotion of seed vending would help in sourcing for seeds that are in low supply. This would, however require quality control measures to ensure only high quality seeds are sourced. The adoption of the proven soil improving agroforestry tree species has remained low due to unavailability of cheap planting materials. Farmers usually prioritize paying for food, fertilizer and school fees over tree planting thereby concluding that poverty and lack of food security can constrain adoption of agroforestry technologies

Adapting agroforestry to farming systems is a major challenge to food production considering the complex tree-crop interactions. For better use of trees in agroforestry systems, it is important to understand the biophysical adaptability of the commonly grown multipurpose woody trees and/or shrubs (Bationo *et al*., 2008). One of the most cited challenges is light competition between the crops and trees. Kater *et al*., (1992) stated that differences in yields under crowns of varying sizes and shapes indicate an effect of light competition between crops and trees. If competition is to be minimized, tree planting must be combined with appropriate management practices such as crown and root-pruning. The possibility of increasing crop yields by increasing their exposure to sunlight is a strong argument for pruning. Experiments on *Cordyla pinnata* in Senegal (Samba, 1997) and *Azadirachta indica* in Burkina Faso (Zoungrana *et al*., 1993) indicate that crop yields under pruned trees are generally higher than under unpruned trees.

However, soils under mature parkland tree canopies are generally more fertile than those in the open due to limited availability of leaf litter (Boffa, 2000). Cannell *et al*., (1996) argued that agroforestry may increase productivity provided the trees capture resources which are under-utilized by crops. Competition for below ground resources between trees and food crops can mask or suppress many of the advantages that trees may provide for long term sustainability of agroforestry systems (Van Noordwisk and Purnomoshidi, 1995). Therefore, there is need to select trees with desirable root and shoot architecture that will be compatible with food crops under different agroforestry systems (Bationo *et al*., 2008). Harborne (1977) also proved that some higher plants (tree crops) release some phytotoxins into the soil, which adversely affect the germination and yield of crops.

Future plans to tree planting

Out of the total respondents, 93 % had plans to plant more trees in future, 6.3 % had no plan and 0.7 % were not sure. In all the cases reported not to have future plans of planting trees, they cited small land as their reason. For those who would like to plant more trees, the more preferred tree species include *Grevillea robusta* (34.7 %), *Persea americana* (14.3 %), *Mangifera indica* (10.9 %) and *Eucalyptus spp* (10.1 %) (Table 14).

Table 14. The ten future preferred tree species of Muranga County

Future preferred tree species	Frequency (%)
Grevillea robusta	34.7
Persea Americana	14.3
Mangifera indica	10.9
Eucalyptus spp	10.1
Macadamia spp	4.1
Cupressus lusitanica	3
Indigenous trees (unspecified)	3
Citrus spp	2.6
Prunus africana	2.2
Cordia africana	1.8

Reason for future tree species preference

The future preferred tree species were based upon various issues(Table 15). The species that provided income in one way or the other rated the highest. Next was the need for provision of timber, fuelwood, and fruits. Some tree species attributes such as low competition with agricultural crops and fast growth also featured prominently.

Table 15. Major reasons for tree species preference

Reason for tree species preference	Frequency (%)
Income	23.6
Timber	20.7
Fuelwood	14.7
Fruits	13.8
No competition with other crops	8.9
Grows fast	4.9
Soil conservation	4.3
Fence/ security	1.4
Aesthetic beauty/ shade	1.2
Fodder	1.2
Able to respond after management	1.2
Medicinal	.9
Windbreak	.9

Elsewhere, Faye, *et al* (2010) prioritized tree functions in west Africa as medicine, human food, fuel, wood, animal food, soil fertility improvement, revenue regeneration, shade and soil and water conservation in that order of importance. Farmers have high preference for 'premium' native trees, i.e. those with high quality by-products and multiplicity of uses, both economic and ecological. High ratings were also recorded for three common exotic tree species, namely *Gmelina arborea*, *Swietenia macrophylla* and *Leucaena leucocephala*.

Future preferred tree planting niche

Most of the farmers with future plans to plant more trees preferred planting them at the boundaries (Table 16).

Table 16. Future preferred tree planting niches

Future preferred tree planting niche	Frequency	Percent
Fence/ Boundaries	90	35.7
Scattered on farm	82	32.5
Homestead/ compound	29	11.5
Woodlots/ fruit orchard	29	11.5
Contour terraces	17	6.7
Riverine	4	1.6
Quarry	1	0.4

The next closely popular site for future tree planting is when scattered on farms intermixed with other agricultural crops (32 %). Woodlots and trees planting on homesteads tied as the third most preferred sites for future tree planting.

Conclusions and recommendations

Most farms had trees during time of acquisition and there have been changes in their species composition to cater for the farmers preferences. The types of tree species grown also conform to the degrees of land elevations. *Grevillea robusta* was most popular tree species in the region. Most trees are grown scattered on farm together with crops.These results showed that it is important to ensure that promotion of agroforestry will translate to tangible economic benefits for farmers. More research should be conducted to focus on fast growing, system compatible and marketable tree /shrub species for future ease of adoption by farmers. The results need to be shared with various stakeholders having an interest in the county.

Acknowledgement

The authors thank KEFRI through the Deputy Director, Socio-economics Policy and Governance, for providing funds. Several local guides and Muranga farmers for providing the useful information, KEFRI staff in central highlands eco-regional program who participated in data collection, analysis and report writing as well as supporting logistically. To all God bless.

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Adoption of *Calliandra calothyrsus* for Improved Dairy Production in Embu County, Kenya

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Abstract
Small-scale dairy production plays a significant role in food production and income generation in Embu County. However, dairy animals in the county rarely meet their full potential of milk production mainly due to inadequate fodder in terms of quantity and quality. Napier grass (*Pennisetum purpureum*) is the main feed for the animals. However, Napier grass is low in protein and produces little biomass during the dry season. Leguminous fodder trees including *Calliandra calothyrsus* are evergreen even during the dry season and have foliage rich in protein which can supplement the main diet of animals. This study was undertaken in Embu County in 2015 to assess adoption of *Calliandra calothyrsus* as a fodder. The study was conducted through a field survey using a structured questionnaire. The study involved interviewing 184 farmers, of which 124 were agroforestry farmers producing fodder trees and 60 non-fodder tree producing farmers. The results of the survey showed that 86% of the sampled farmers had adopted growing of Calliandra tree fodder. These farmers noted that the tree had multiple benefits that included; increased and improved dairy milk production from cows and goats as indicated by about 92% of the farmers, and improved quality of manure (84%). Age, gender, years in education and land size were the key socio-economic factors influencing adoption of Calliandra. *Calliandra calothyrsus* is an important fodder tree in Embu County contributing to; increased and improved milk production, providing food supplement for other livestock enterprises, conservation of soil and improved quality of manure.

Keywords: Dairy farming, Embu County, *Calliandra calothrysus*, Adoption, Agroforestry

Introduction

Kenya's economy is heavily reliant on agriculture. The sector contributes 30% of Kenya's Gross Domestic Product and accounts for 80% of the national employment (GOK, 2010). Agriculture is the primary source of livelihoods for the many small scale land holders. Any adverse effects on the agricultural sector directly compromises economic development, food security and poverty alleviation in Kenya. The major challenge for smallholder farms in Kenya is to meet the ever growing demand for agricultural products while conserving biodiversity, providing critical ecosystem services and maintaining rural livelihoods (Barrios, 2007; Harvey *et al*., 2008). The farming sector faces numerous challenges including declining productivity of both crops and domestic animals, overgrazing, land degradation and soil erosion, hence the need to adopt more sustainable agricultural practices. Agroforestry is a promising alternative to overcome this challenge. Agroforestry is an integrated approach which combines sustainable farming production and biodiversity conservation (Jerneck and Olsson 2013; Pretty *et al*., 2006). Over the years agroforestry practice has been recognised as an important tool in meeting ecological, economic and social needs of humans. The adoption of agroforestry practices including fodder shrubs is considerably more complex than traditional agriculture because it usually requires establishing a package of activities which integrates trees, crops and livestock and other components, combined with new conservation techniques such as contour hedgerows, wind breaks, alley cropping, and enriched fallows (Hyde and Köhlin, 2000).

Dairy farming for many Kenyan small scale farmers is an important venture due to its contribution to household incomes, food security and provision of manure for crops (Karanja, 2003), the potential for milk productivity has been low, for instance in Embu County milk productivity at farm level was reported to be on average about 8 kg/cow/day (Minae and Nyamai, 1988; Murithi, 1998). This can be improved through better use of available resources and current state of technology (Mugambi, 2014). Inadequate and low-quality feed is a major cause of low dairy animal productivity. Fodder shrubs such as *Calliandra calothyrsus* provide valuable feed supplements to dairy animals especially during the dry season when the basal diet Napier grass is low in protein and produces less biomass (Minae and Nyamai 1988). Unlike conventional agriculture, the system is more knowledge-intensive. *Calliandra calothyrsus* is a leguminous tree that originates from Central America and Mexico (Gutteridge and Shelton, 1994). It is a large multi-stem shrub growing to a height of 4 to 6 m (Maundu and Tengnas, 2005). The shrub grows well on a broad range of soil types ranging from deep volcanic loams to more acidic metamorphic sandy clays. Calliandra grows at an altitude from 0 to1, 850 metres above sea level. The maturity period for fodder production after planting is 8to12 months (Cook *et al*., 2005). Calliandra leaves when fed fresh was found to have about 24% to 28% crude protein. There are numerous benefits attributed to adoption of fodder technologies among rural households in Kenya. However, few studies have been conducted to examine the benefits of adopting fodder agroforestry practices. The objectives of this study were to; assess the benefits of fodder technology, determine factors influencing its uptake, identify constraints and the most efficient technology dissemination pathways.

Materials and methods

Study Site

Embu County covers an area of 2,818 square km with a population density of 183 people per square km. In addition, the county receives a bimodal rainfall pattern, with the peak rainfall occurring between March and June, and short rainfall between October and November. On average the rainfall ranges between 1,200 to 1,500 mm annually. Temperatures range from a minimum of 16 C to a maximum of 23 C. The main cash crops grown were coffee and tea, while food crops were maize and beans. Dairy farming is a major activity in the county. The study was carried out in Embu County in the eastern region of Kenya formerly known as Eastern Province (Figure. 1). Dissemination of fodder technologies in the County was undertaken jointly by National Agroforestry Research Project (NAFRP), Kenya Forestry Research Institute (KEFRI) Kenya Agricultural Research Institute now Kenya Agricultural

Livestock Research Organization (KALRO) and International Centre for Research in Agroforestry (ICRAF) in the early 1990's. The objective of the project was to introduce and promote a package of agroforestry fodder species namely that included; *Calliandra calothyrsus*, Leucaena species, *Pennisetum purpureum*, *Tithonia diversifolia*, *Morus alba*, *Ficus thonningii* and *Grevillea robusta*. The project targeted 150 farmer groups comprising 2,600 farmers. On average each farmer received 400 fodder shrub seedlings of assorted target species.

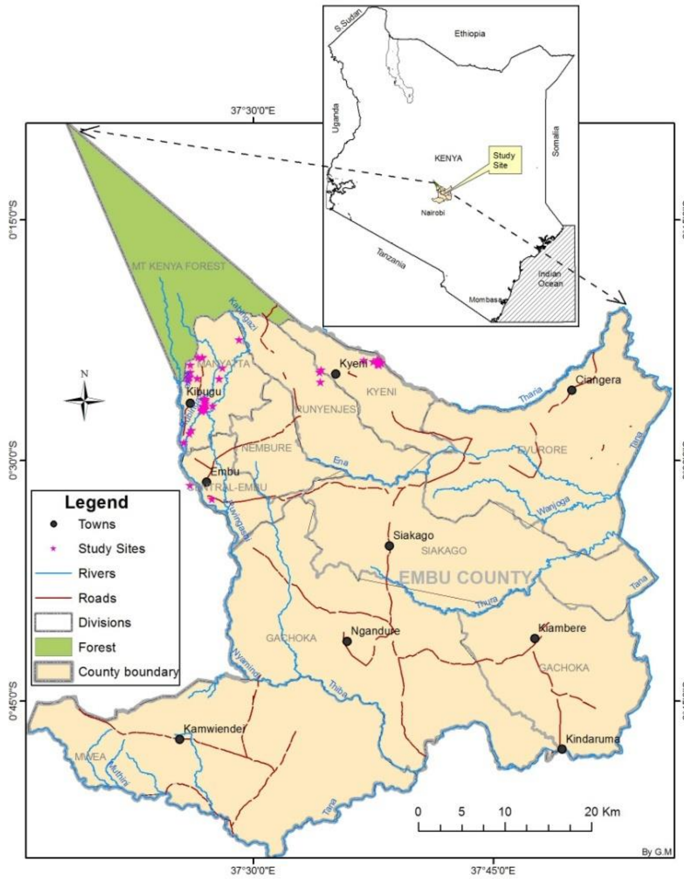

Figure 1. Study site showing sub-counties in Embu County

Data collection and analysis

Data was collected in 2015 from farmers who adopted the technology and non-adopters residing within the areas where Calliandra was introduced. A structured questionnaire was administered to 124 farmers planting and using fodder plants and 60 non-adopters. The data was entered and analysed using SPSS statistical software. Descriptive statistics were used to assess the benefits accruing from growing of fodder trees, the household and land characteristics influencing adoption. To determine the factors influencing the adoption of fodder technologies the logistic regression model was applied.

Results

Socio economic and demographic characteristics

The study findings revealed that the initial project farmers and adopters were relatively older with mean ages of 62 and 58 years respectively as compared with non-adopters who were much younger with a mean age of 35 years (Table 1). Land size varied with the original farmers having the largest farm size with a mean of 2.4 acres; adopters had a mean land size of 2 acres while non-adopters had the smallest landholding with a mean of 1.2 acres.

Table 1. Farmer demographic characteristics and their farm sizes

Type of farmer	Variable	N	Minimum	Maximum	Mean	Standard deviation
Original	Age (years)	62	35.0	96	62.2	15.0
	Farm size (acres)	62	0.3	9	2.4	1.80
Adopters	Age (years)	62	30.0	90	58.4	15.4
	Farm size (acres)	62	0.1	6	2.0	1.50
Non-adopters	Age (years)	60	28.0	87	15.3	13.6
	Farm size (acres)	60	0.1	5	1.2	0.9

1 acre = 0.4 ha

In terms of gender, male farmers dominated female counterparts in all the three categories (Table 2). Among the adopters, 84.1% were male while 15.9% were female. While in the non-adopters category 88.3% were male and 11.7% were female.

Table 2. Gender percentage distribution by type of farmer category

Type of farmer	Gender	Frequency	Percent
Original	Male	51	83.6
	Female	10	16.4
	Total	61	100.0
Adopters	Male	53	84.1
	Female	10	15.9
	Total	63	100.0
Non-Adopters	Male	53	88.3
	Female	7	11.7
	Total	60	100.0

Concerning farmers level of education 85.3% accessed formal education with 50.5% of them attaining primary education, 29.9% attained secondary and only 4.3% attained tertiary education. On occupation, 70% of the respondents had farming as main occupation 19.7% engaging in business, 11% salaried employment and 2.7% work as casual labours (Table 3).

Table 3. Education level and main source of income of the household head

Education level	Frequency	Percentage
None	27	14.7
Primary	94	50.5
Secondary	55	29.9
Tertiary College	8	4.3
Total	**184**	**100.0**
Main source of household income		
Salaried employment	20	11.0
Farming	182	70.0
Casual labour	7	2.7
Self-employed business	51	19.7
Total	**184**	**100.0**

Majority of the farmers owned land privately (79.8%), and few (19.7%) had land that was under family or communal land tenure systems (Table 4). About 61% of the farmers had title deeds of their land, indicating secure land tenure, which can consequently encourage farmers to plant and adopt tree fodder technologies. Regarding land topography in the sampled farms 49.1% of farms were slightly sloppy, 25.9% very sloppy and 25% were relatively flat.

Table 4. Land tenure and topographic characteristics of sampled farms

Land ownership	Frequency	Percentage (%)
Individual	150	79.8
Family	37	19.7
Total	**184**	**100.0**
Title deed		
Yes	113	61.1
No	71	38.9
Total	184	100.0
Land gradient		
Flat	46	25.0
Slightly sloping	90	49.1
Very sloppy	48	25.9
Total	**184**	**100.0**

Fodder utilization and benefits

The study showed that the number of households who had adopted the fodder technology utilised it under various livestock enterprises within the farm. *Calliandra calothyrsus* was the most adopted and utilised shrub in the farm with a majority of the farmers utilising it in all the livestock enterprises followed by *Morus alba* (Table 5).

Table 5. Agroforestry technologies package use across the livestock enterprises

	Promoted fodder technologies						
Livestock type	*Calliandra calothyrsus*	Leucaena species	Napier grass	*Tithonia diversifolia*	*Morus alba*	*Ficus thonningii*	**Total**
Dairy cattle	89	0	1	2	4	0	97
Goats	56	2	0	1	3	1	63
Poultry	38	0	0	2	1	0	41
Beef cattle	30	0	0	1	0	0	32
Rabbits	20	0	0	0	1	0	21
Sheep	18	0	0	1	1	0	20
Bees	7	0	0	0	0	0	7
Fish	3	0	0	0	0	0	3
Pigs	2	0	0	0	0	0	2

Fodder trees have multiple benefits to the farming system. The benefits included; increased and improved milk production from dairy cows and goats as noted by 92% of the farmers, improved quality of manure (84%) and increased egg production (84.6%). Other benefits that accrued to the household included improved quantity and quality of; beef (100%), fish (100%), maize beans (97.2%), rabbits (100%) and honey (84.6%) as illustrated in Table 6.

Table 6. On-farm benefits of promoted fodder technologies

Farm Product	**Production**				**Quality**			
	Increased		No change		Improved		No change	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Cow milk	81	92.0	7	8.0	79	91.9	7	8.1
Goat milk	44	91.7	4	8.3	44	91.7	4	8.3
Eggs	11	84.6	2	15.4	12	92.3	1	7.7
Honey	11	84.6	2	15.4	11	84.6	2	15.4
Fish	4	100.0	0	0.0	4	100.0	0	0.0
Manure	84	96.6	3	3.4	84	97.7	2	2.3
Maize	77	97.5	2	2.5	76	97.4	2	2.6
Beans	70	97.2	2	2.8	69	97.2	2	2.8
Beef	9	100.0	0	0.0	9	100.0	0	0.0
Rabbit	4	100.0	0	0.0	4	100.0	0	0.0
Bananas	4	100.0	0	0.0	4	100.0	0	0.0

Adoption of agroforestry technologies

The rate of adoption of fodder technologies was determined by the number of sampled farmers who allocated or planted the fodder trees on their farms and utilising them for various uses. From the study, 86% of the sampled farmers had adopted the technology. Further analysis to determine the number of adopters who had disseminated the technology to other farmers was undertaken. From the analysis, original project farmers had disseminated the technology to more farmers as compared to the adopters (Table 7).

Table 7. Number of farmers the technology was disseminated to by original famers and adopters

Type of farmer	Number and percentage of farmers the technology was disseminated to				
Range	<100	100 to 200	200 to 300	>300	Total
Initial	46	2	2	2	52
	88.5%	3.8%	3.8%	3.8%	100.0%
Adopters	30	2	0	2	34
	88.2%	5.9%	0.0%	5.9%	100.0%
Total	76	4	2	4	86
	88.4%	4.7%	2.3%	4.7%	100.0%

Determinants of agroforestry fodder technology adoption

Various socio-economic factors influence technology adoption and uptake among farmers. Logistic regression was performed to ascertain the effects of gender, age, the level of education, the major source of income, primary source of expenditure, land ownership, land size, and land tenure, and farm gradient on the likelihood of adoption of fodder technology. The results from the regression analysis (Table 8) indicate that the model was statistically significant, $\chi^2_{(3)}$=16.661, P-Value<0.0005. The model explained 31.0% (Nagelkerke R^2) of the variance in the adoption of agroforestry technologies. Socio-economic factors; age, gender, years in education, and land size influenced adoption of agroforestry techniques. The likelihood to adopt was positively related to age. The number of years in education had a positive influence.

Table 8. Logistic regression model for determinants of adoption of fodder technologies in Embu County

Variables in the Equation	B	S.E.	Wald	Sig.	Exp (B)	95% C.I for Exp(B)	
						Lower	Upper
Gender	-1.053	.373	7.983	.005	7.3	.168	.724
Age	.027	.017	7.440	.008	1.0	.993	1.062
Level of education	.171	.276	5.383	.036	0.4	.491	1.448
Main source of income	.329	.501	6.430	.012	1.3	.520	3.711
Major source of household expenditure	.124	.163	3.581	.146	1.1	.823	1.557
Land ownership	20.155	22636.24	.000	.999	566246583.3	0.000	
Land size	.430	.201	4.556	.033	1.5	1.036	2.280
Land tenure	-.051	.496	.011	.918	.9	.359	2.512
Farm gradient	-.037	.272	6.018	.202	.9	.565	1.643
Constant	-20.116	22636.243	.000	.999	.000		
Test statistic: $\chi^2_{(3)}$=16.661, P-Value<0.0005, 31.0% (Nagelkerke R^2)							

Discussion

The findings indicate older farmers were more receptive to the fodder technology than young ones. This can be attributed to the fact that the Calliandra project may have targeted the older farmers. However, age may constrain the adoption of fodder technologies since older farmers may not be enthusiastic to plant trees whose benefits are not immediate (Jera and Ajayi, 2008). Land size had a positive influence on adoption of agroforestry practices. Farmers adopting the fodder technologies had larger land sizes than non-adopters indicating direct relationship between land size and rate of adoption. This finding is in tandem with results of Ajayi *et al*., (2008) who found that land size has a positive influence on adoption of new technologies. Rana *et al*., 2000 and Fernandez-Cornejo *et al*., 2001 also reported that large farm sizes have a positive effect on adoption of agricultural technologies. Gender analysis indicated that male dominated female counterparts in the adoption of fodder technologies. The difference can be attributed to the fact that unlike men, women in majority of Kenyan communities have neither right to own agricultural production resources especially land nor power to make major decisions regarding agricultural productions and this renders women unable to acquire and use new agricultural technologies. The findings concur with that of Masuki *et al*. (2003). The low percentage of farmers with tertiary education can be attributed to the fact that farmers tend to engage in off-farm activities as education level increases (Akkaya *et al.*, 2007). Findings of the study agreed with Boateng (2008), who found that high level of literacy would result in an increase in technical efficiency and decreased conservatism among farmers. The study revealed that *Calliandra calothrysus* has multiple benefits and has improved the livelihoods of the farmers.

Conclusion

The findings of this study indicate that majority of the older farmers had adopted the growing of fodder trees as they owned the land. Farmers with larger farm sizes adopted the technology. The technology is providing multiple benefits to the farmers and the farming system. The study recommended that farmers should continue adopting fodder technologies for improved livelihoods.

Acknowledgement

We are indebted to KEFRI for the financial support in carrying out this study. Dr Joshua Cheboiwo, Deputy Director, Socio-Economics Policy and Governance for providing financial support for the research. Enumerators who collected the data are also highly acknowledged. Finally, we wish to sincerely thank all the farmers who answered our questions during the survey.

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Gender Related Aspects in Adoption of Biomass Energy Conservation Technologies in Four Selected Areas of Kitui County

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Abstract
This paper examines the influence of gender aspects in adoption and continued use of biomass energy conservation technologies in Kitui County, Kenya. The county suffers increased deforestation, environmental degradation, threatened species and increased food insecurity as result of overexploitation of tree resources for wood fuel production. The government of Kenya in cooperation with development partners developed and promoted energy conservation technologies in the region. Despite these efforts, overexploitation and selective harvesting of wood resources for energy has been rampant. The objective of the study was to determine factors influencing adoption of biomass energy conservation technologies at household and community level. The study was carried out in Kitui Central. Chuluni, Matinyani and Mutonguni sub-counties using a survey design. Structured interview schedule was used to collect data from 192 respondents and thematic guidelines for focus group discussions. SPSS and Excel computer packages were used to analyse data. The results revealed that, at 0.05% level of significance, adoption of improved biomass energy technologies were positively correlated to income and awareness levels. Lack of awareness on improved biomass energy technologies among men, resource ownership, cultural roles and responsibilities, lack of inclusive decision making in most households, low literacy levels among women and over dependence on men and subsistence farming for financial support by women were indicated as some of the factors influencing adoption of improved technologies. The study recommends financial empowerment of women, inclusive decision making, increased awareness on improved technologies to all genders and mainstreaming gender at all levels in project management for increased adoption of technologies.

Keywords: Biomass, energy, gender, improved technologies, environment

Introduction

Increasing interest in renewable energy resources including biomass energy as source of energy for over a third of world's population has increased their role in sustainable development. In developing countries, biomass energy is predominantly used in form of fuel wood, charcoal, bio-fuel and agricultural wastes or briquettes, and accounts for nearly 80% of the total renewable energy supply worldwide (FAO, 2010). Globally, the demand for biomass energy for cooking and heating has been on the rise due to increasing population, rapid urbanization and increasing demands in the commercial and institutional sectors. Unsustainable energy production and consumption has been attributed to changing environment, with 20 to 30% of global emissions attributed to the energy production and utilization and about 7% of deforestation in the world also associated to biomass energy extraction and processing (WHO/UNDP, 2016). Increased use of biomass energy is also associated with increased respiratory diseases and according to world health organization (WHO), over 4.3 million people worldwide in 2012 suffered from respiratory and cardiovascular diseases related to use of solid fuels used in poorly ventilated housing units (WHO/UNDP, 2012), majority of whom are women, children and the elderly. In Sub-Saharan Africa (SSA) men and women are dependent on biomass energy in form of wood fuel, agricultural and forestry wastes, where it accounts for up to 90 percent of energy use for cooking and heating (UN, women Watch, 2009, WHO/UNDP, 2009). Majority of this fuel comes from unsustainable sources such as dry forests and woodlands, with forestry sector accounting for 87 % of supply of biomass (WBA, 2017). With increasing demand both for domestic and commercial purpose, the ability of men and women to obtain these indispensable resources is reduced especially with effects of climate change (UN, women Watch).

In sustainable natural resource management, gender inequalities in areas such resource ownership, land tenure systems, access to resources, education, accessibility to extension and health services have contributed to lower agricultural productivity, lower adoption of technologies and higher poverty levels especially among the women (WEO, 2002, FAO, 2006). The issue of resource ownership, land and tree tenure systems which favours men in terms of access and control of resources leaves women disadvantaged in terms of making decisions concerning technology adoption within the households. With limited land rights and incomes, women have restricted access to credit facilities and little incentive to invest in better management and conservation practices (FAO, 2006), hence the low adoption of biomass energy conservation technologies. It is therefore important to identify gender-sensitive strategies to respond to the energy and environmental degradation crisis, as women are more dependent on natural resources for their livelihoods.

In Kenya, wood based energy provides 70% of the national energy needs with about 90% of Kenyan's rural households depending on fuel wood as basic source of energy while it is estimated that 83% of Kenyan urban households depend on charcoal for cooking (MoE, 2012). Wood fuel energy is also an important source of energy for small scale commercial enterprises (SMEs) (Githiomi and Oduor, 2007) and institutions such as schools, prison, and hospitals. Increasing populations, high poverty rates, rapid urbanization, and high cost of alternative fuels, are some of the factors associated with increasing demand and the trend is expected to continue to foreseeable future. In most of cultured communities, women and children are charged with the responsibility to secure food and fuel for cooking and heating. With increasing degradation and depletion of natural resources, the collectors are forced to spend more time, carry heavy loads and walk long distances in search of the resources (FAO 2006). Coupled with unequal access to resources and to decision-making processes, women in rural areas are greatly being affected by impacts of environmental degradation (UN-women Watch, 2009). As a result of these challenges and negative impacts to the people and the environment, a number of biomass energy conservation programmes have been rolled out in Kenya to promote energy efficiency, improved livelihoods and environmental conservation. These programmes are meant to minimize impacts of unsustainable production and utilization of biomass energy on the environment and the people, especially the collectors who are mainly women and children.

Kitui County is one of the Arid and semi arid lands (ASAL) counties in South Eastern Kenya. Subsistence mixed agriculture and horticulture is the back bone of the County and is carried out mainly in the central part of the County. In the lowlands, livestock and charcoal production supplement crop farming as source of income especially during prolonged droughts. Overexploitation of wood resources to meet domestic and commercial energy demands has led to wood scarcity, loss of biodiversity, environmental degradation and prolonged droughts thus food insecurity.

To curb on the negative impacts to the people and the environment, a number of organizations developed and disseminated information and skills on biomass energy conservation technologies to local communities and institutions within the county. The technologies included energy saving cook stoves, improved charcoal conversion kilns and establishment of woodlots for increased resource production. The technologies aimed at reducing the amount of fuel used for cooking and heating, reduce deforestation, save time and energy spend by collectors for other economic activities and lastly, increase tree cover through establishment of wood fuel plantations. Despite the high number of actors involved in research, development and dissemination of information on technologies, adoption and continued use of the technologies still remains low. Lack of information and technical skills, financial constraints, cultural preferences, high cost of improved technologies and lack of application of gender analysis to ensure preferences and priorities of different group and communities in providing appropriate energy choices has led to low adoption of the technologies. However, no studies have been undertaken to establish the role of the gender related aspects in influencing the adoption of biomass energy conservation technologies in the County. This study therefore sought to assess the influence of gender aspects in the adoption of energy conservation technologies in the study area.

The main objective of the study was to assess factors influencing adoption of biomass energy conservation technologies in four selected areas of Kitui County. The specific objectives of the study were to establish the Socio-economic and demographic characteristics of the respondents in the study area, establish energy conservation technologies used by the community and to investigate how socio-economic factors including gender related aspects influence decisions on adoption of biomass energy conservation technologies at household level in the County.

Study methodology

Study Area

The study was undertaken in four selected areas of Kitui County namely: - Kitui Central, Chuluni, Matinyani and Mutonguni (Figure 1) The County total area is 30,496.4 km^2 (KNBS, 2015) and has two rainy seasons with low and erratic rains ranging from 250 mm to 1050 mm per annum with 40-percent reliability. The 2009 Kenya Population and Housing Census report puts the population of the County at 1,012,709 persons (KNBS, 2010).

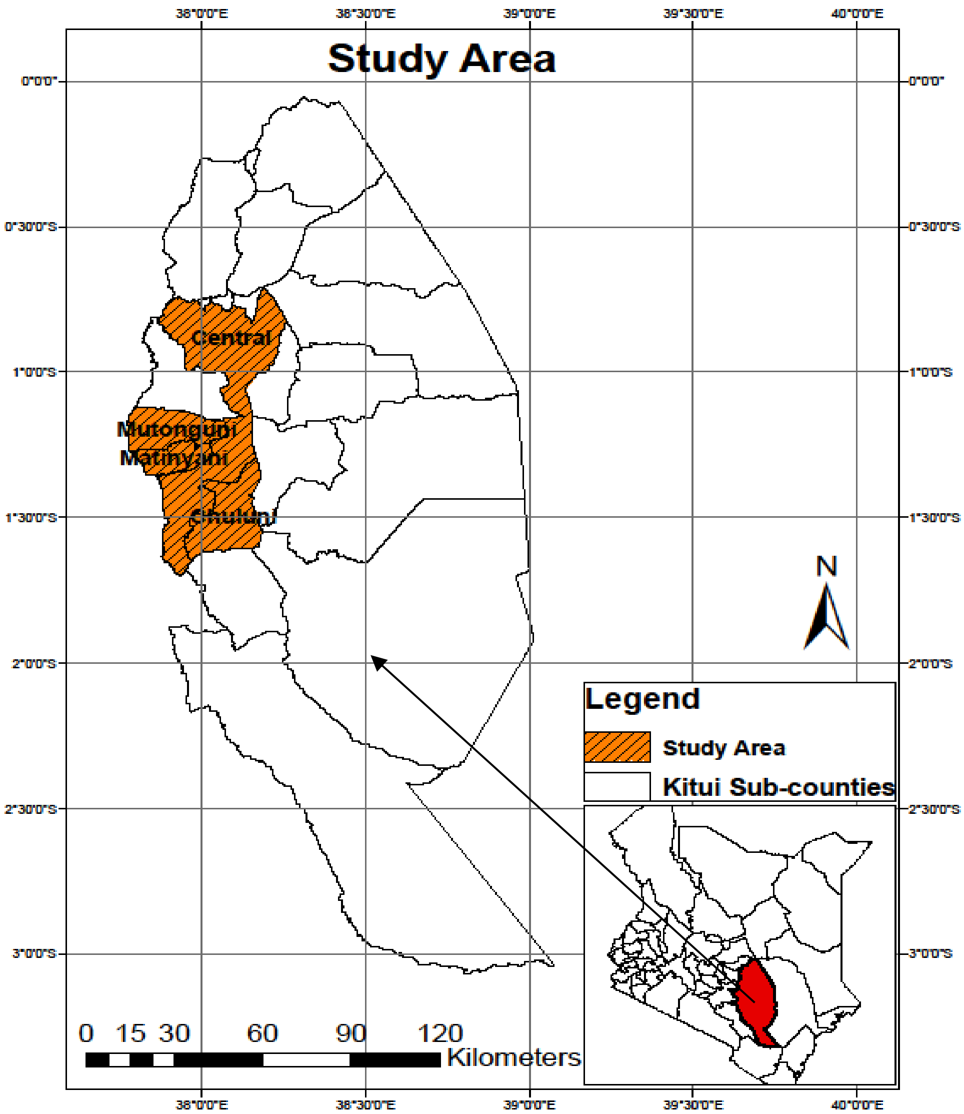

Figure 1. Map of the study area- Kitui County

Subsistence mixed agriculture and horticulture is the back bone of the County and is carried out mainly in the central part of the County. In the lowlands, livestock and charcoal production supplement crop farming as source of income especially during prolonged droughts. (GOK, 2013). The study target areas falls in the central parts of the County which is characterized by moderate rainfall (700 mm to 1050 mm) and high population densities of 55 persons /km^2 higher than the county mean density of 33 persons/km^2. The area also has potential for tree growing, crop production, dairy and horticultural produce (GoK, 2011). Due to population pressure, the central area is also characterised by small land sizes thus putting a lot of pressure on available forest/tree resources.

Sampling and data collection

The study area was stratified into Sub-counties, then locations and lastly sub-locations as the sampling units. Semi structured questionnaires were administered to 192 respondents and thematic guidelines for community focus group discussions for more information on socio-economic and environmental factors influencing adoption biomass energy in the study area.

Data organization and analysis

Data collected was coded and analyzed using Statistical Package for Social Scientists (SPSS) and Microsoft Excel computer packages for descriptive and inferential statistics

Results and Discussions

Socio-economic and demographic characteristics of the respondents

Head of households and decision making

The study revealed that more men (61.9 %) than women (39.1 %) as indicated in Table 1 were head of households. The women headed households included single parents and windows who were mainly elderly women. As head of households, men were noted to be the main decision makers on all development matters in the households including adoption of any new technology in the households.

Table 1. Head of households (%)

Study Areas	Gender	
	F	M
Mutonguni	40.2	59.8
Kitui Central	39.8	60.2
Matinyani	38.6	61.4
Chuluni	37.8	62.2
Mean	**39.1**	**61.9 %**

Decision making in the households

On who should make decisions in the households, results indicated 59.25 % of the respondents as in Table 2 indicated that, men as head of household ought to be the main decision maker on all matters in the households concerning technology adoption including those touching on energy issues which falls under the women docket. This has affected adoption of technologies such as establishment of woodlots for wood fuel production, as men dictate on choice of planting sites and species for biomass production. Men's preference for multipurpose trees for timber, poles and posts other than the preferred trees for wood fuel production means fuel wood will only be obtained after the trees have been harvested for those other purposes. In earlier studies in the community (*Muok et al, 2002*), tree planting as an activity is a preserve of men and are the main decision makers and women will only plant trees with authority from men even in absentia or if windowed. This has affected establishment of woodlots by the women as a technology for energy provision and conservation through increased resource production.

Table 2. Decision making by gender on energy conservation technologies (%).

	Gender	
Study areas	**Men**	**Women**
Mutonguni	68	45
Kitui Central	58	32
Matinyani	62	36
Chuluni	59	51
Mean	**59.25**	**41.25**

Over half of the respondents (59.25 %) indicated in Table 2, men were indicated as suitable to make decisions concerning adoption of new technologies in the households.. Culturally, men as head of households are bestowed the role of decision makers and this gives them opportunity to make decisions sometimes arbitrary without consulting other family members including the women. Lack of participation in decision making, denies women the opportunity to make decisions on adoption of new technologies which will affect their productive and reproductive roles such as tree planting for wood fuel production. The women cannot make any decision on their own and have to seek consent from the husbands majority of whom are absent from home most of the time in search of alternative livelihoods and cannot participate in information and dissemination activities like trainings where most of the technologies are disseminated thus have to rely on second hand information. Lack of inclusive decision making processes in most households due to cultural aspects leaves women disadvantaged in terms of making decisions concerning technology adoption within their households and this affects adoption and continued use of any new technologies including energy conservation technologies . A situational analysis of Kenyan women by UNICEF (Mutavi *et al*,. 2013) presents women as marginalized in the area of property ownership, decision making and management in agriculture compared to men and this affects any decision on adoption of technologies on farm that would improve their productivity.

Sources of incomes and decision making at household levels

The improved technologies were indicated as expensive compared to the traditional ones and the financial aspects related to procurement and installation or establishment of this technologies such as woodlots could be the main reason men were indicated as suitable decision makers as they are head of household and financiers of most development activities at household level. Men with higher disposable incomes and more stable sources of incomes (62 %) than women as indicated in Figure 1 had opportunity to invest on energy conservation technologies than women whom than women who relied more on subsistence farming as source of income.

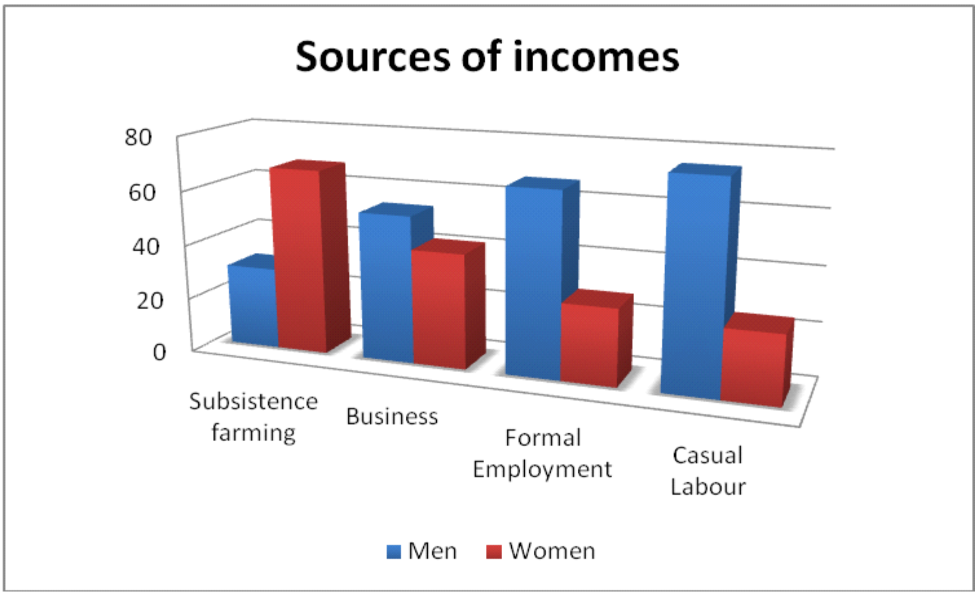

Figure 2. Sources of incomes for Men and women

With changing climatic conditions, the reliability of the rains has become lower, thus crop failure has become more frequent. This coupled with small land sizes and large families with a mean of seven members per household within the study area, , most of the food crop produced goes towards feeding the families and with few alternative income generating activities, women are thus financially constrained and cannot afford to spend monies outside the family's basic needs. Over dependence on subsistence farming by the women and lack of credit facilities to boost their farm production capacities, explains why most of the women lack financial resources to invest in acquiring new technologies such as improved energy technologies thus low adoption of the technologies. In reference to costs of improved technologies which was higher than the traditional technologies, education levels of the women and energy conservation technologies adopted , there is a significant correlation between income sources/levels and energy conservation methods, p=0.000 as indicated (Table 2).

Table 3. Correlation analysis between income sources, education level and adoption of technologies

		Source of income	Education level	Energy conservation methods
Source of income	Pearson Correlation	1	.070	.433**
	Sig. (2-tailed)		.338	.000
	N	441	188	231
Education level	Pearson Correlation	.070	1	-.009
	Sig. (2-tailed)	.338		.915
	N	188	189	159
Energy conservation methods	Pearson Correlation	.433**	-.009	1
	Sig. (2-tailed)	.000	.915	
	N	231	159	249

** Correlation is significant at the 0.01 level (2-tailed).

From the results, households with higher levels of income had higher levels of adoption of the energy conservation technologies. This means with improved income sources within households and more alternative sources of income among the women, adoption levels and continued use of the energy conservation technologies will increase.

Influence of information and skills

Lack of expertise and information was indicated by 36.1 % of the respondents as one of the factors influencing adoption of improved energy conservation technologies (Table 4).

Table 4. Socio-Economic, Technical and Environmental Constraints to Adoption of Energy Conservation Technologies (%)

Constraints	**Cultural preferences**	**Lack of Finance**	**Lack of credit facilities**	**Availability of other alternative fuels**	**Trees for wood fuel still on farm**	**Lack of expertise and information**	**Lack of follow-up programme**	**Lack of sharing of information**
Mutonguni	55.5	59.3	51.8	32.5	32.6	39.5	55.1	33.5
Kitui Central	41.5	57.8	45.3	33.3	27.5	33.3	45.1	46.7
Chuluni	60.5	65.6	40.9	35.8	43.9	32.6	88.3	40.9
Matinyani	56.4	63.5	35.8	38.2	33.4	42.5	67.5	38.8
Means	**53.5**	**61.55**	**43.5**	**35.1**	**34.1**	**36.1**	**56.5**	**39.1**

Though, generally, literacy levels in the study area are lower than the national averages which according to World Bank report of 2014 places Kenya's adult literacy levels at 79 % , about 62 %) of the respondents had completed primary education as their highest level of education attained while those with secondary and tertiary were at 31 % and 2 % respectively among the respondents. However, women formed majority of those having lower education or no education at all as indicated in (Table 5).

Table 5. Education levels of the respondents by gender (%

Study areas	**None**			**Primary**			**Secondary**			**Tertiary**		
	F	**M**		**F**	**M**		**F**	**M**		**F**	**M**	
Mutonguni	3.5	1.4	**4.9**	26.0	22.5	**58.5**	10	18	**28**	0	0	**0**
Kitui Central	3.2	1.3	**4.5**	35.5	33.3	**68.7**	14	20.4	**34.4**	1	1	**2**
Matinyani	3.6	2.0	**5.6**	33.0	32.3	**69.3**	15	20.2	**35.2**	0	1	**1**
Chuluni	2.7	2.0	**4.7**	22.3	22.0	**54.4**	10	17	**27**	0	1	**1**
Total Mean			**4.925**			**62.475**			**31.15**			**2.0**

Though men had a higher literacy levels according to the study, their participation in the study as respondents was noted to below at (15 %) and women at (85 %) due to absence from home. home. This denies them the opportunities to participate in information dissemination activities, hence lack the necessary information on improved biomass energy technology. This has led to less investment on the bio-energy technologies they know very little about.

On the other hand, though women are available, their low literacy levels compared to men as women formed majority (75 %) of those with little or no education at all., affects their active participation in information dissemination such as trainings and use of extension materials. This means. It also affects their knowledge level and understanding of the technologies, the benefits accrued from using them in their production and on their health. In a related study according to Kiptot, et al (2014), it was reported that only 15 % of extension agents disseminating information on agricultural technologies are women while only 5 % of the women receive extension services in Africa. Men with higher literacy level, are in a better position to participate in the information dissemination activities, however their continued absence from home and villages most of the times, leaves a gap for information in most households. With lack of information and skills, women are unlikely to adopt technologies they know and understand little about and this affects adoption and continued use of biomass energy conservation technologies.

Biases in land tenure systems and resource ownership

Land ownership and tree and land tenure systems are among factors noted to hinder technology adoption in the study area. From the results, while most of the land is private and public owned at 72.4 % and 25.7 %, respectively, as indicated in (Figure 3), Over 80 % of the private land is registered in men's name except where land was jointly bought by both man and the wife.

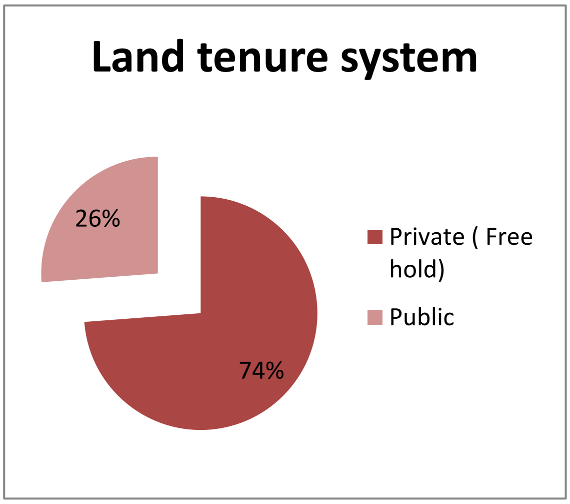

Figure 3. Land tenure system in the study area

While the current Kenya constitution (2010) allows women to inherit and own family land, however, the silent cultural law favors men in the registration of family land. Under the Kenyan law, the private or freehold gives the holder of the title deed unconditional ownership of the land without any limitations regarding use or occupation (Kanyinga *et al.,* 2008). Though women have "free access" to land, most of the land is registered under men's names and is absolutely under their control. This gives them absolute authority to make any decision concerning any development on the farm, especially any long term investment decision like tree planting or installation of energy conservation technology like a masonry kiln. It is important to note that land ownership and decision making are preserve of men and affects any decision on any permanent development on the land. The issue of land / resource ownership affects adoption of any new technology on the farm even though beneficial to the whole family.

The issue of land and adoption of new technologies becomes even more complicated and a major hindrance to adoption of technologies when land belongs to extended families. These discourages activities like tree planting as trees are considered a long term investment hence no members of the community are willing to invest on land or put up permanent development or installations on land which might be re-allocated to other family member's later on subdivision and thus loss of their investment.

Conclusions and recommendations

The study concludes that adoption of biomass energy conservation technologies that have the potential for improved livelihoods and environmental conservation can be upscaled; however gender related constraints affecting women, which hinder adoption and continued use of available technologies, need to be addressed. These includes; financial constraints among women due to overdependence on subsistence agriculture in the face of changing climate, lack of alternative source of incomes, low illiteracy levels compared to men, lack of inclusive decision making at family and community levels and biases in land tenure and resource ownership systems which favor men especially in the cultural setups. Addressing the gender related challenges affecting women and men, will translate to increased adoption of the energy conservation technologies .The study therefore recommends; Government institutions and development partners to mainstream gender aspects and awareness in community development matters to ensure participation of all members of the community. This will ensure both men and women participate in development related matters such as community trainings that will empower them to acquire knowledge and skills. It will also enable them participate in decisions making on matters touching on activities and technologies which directly influence their lives. In order to uplift poor rural women, there is need also to provide alternative income generating activities which are climate change resilient, so that women can stop relying on subsistence farming as source of livelihood for increased adoption of new technologies.

Acknowledgement

The authors wish to convey their appreciation to the KEFRI Management for financing the study. Special thanks to Celestine Ingutia for assistance in data management and community resource persons in Kitui who assisted in data collection. Lastly, special gratitude to all community groups and members who participated in the study.

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Status and Growth Determinants of Non-Timber Forest Products Firms in Kenya

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Abstract
The nature and state of non-timber forest products small and medium enterprises and what drives their growth in Kenya is not fully understood. Studies done have not adequately described the firms and demonstrate what influence their growth. Thus, this study performed descriptive and inferential statistical analyses to characterize and establish growth determinants of the firms. The study was conducted as a cross-sectional survey with questionnaire administered to entrepreneurs of 314 firms dealing with non-timber forest products selected using stratified random sampling methods from nine representative counties of Kenya. Frequency counts and percentages were used in characterizing respondent firms whereas regression analysis was applied to establish growth determinants. It was observed that most firms were relatively new in operation, small with less than 10 employees, operated as sole proprietorship ventures and dealt with fruit based products. Most entrepreneurs were well educated young adults but had no requisite managerial and social skills, and industry experience. Nature of products and legal status (firm characteristics), and entrepreneur's age and education (entrepreneur characteristics) influenced firm growth. It was concluded that entrepreneurship in non-timber forest products is in nascent stages of growth run with entrepreneurs without requisite qualifications necessary for creating competitiveness and growth of the industry. There is need, therefore for the firms to enhance their capacities through appropriate staff recruitment and development policies. Policy measures are necessary to encourage the many well educated but unemployed youth to engage in businesses. Additionally, firm registration especially incorporating partnerships and limited companies be encouraged and supported.

Keywords: Characteristics, entrepreneurship, firm, non-timber forest products, small and medium enterprises

Introduction
The small and medium enterprises (SMEs) which operate in all sectors make up a significant part of the Kenyan economy (GoK, 2008). These entrepreneurial activities create jobs and enhance economic growth through accelerating innovation and promoting full use of human, financial and other resources. The SMEs have been successfully used by the Western economies for job and wealth creation (Gómez, 2006; Namusonge, 2014). Following suit, Kenya has increasingly put focus on SMEs for ending poverty and building shared prosperity.

In 2011 for example, the SMEs employed close to 80 percent of Kenya's total workforce estimated at seven million persons and contributed 20 percent to Gross Domestic Product ([GDP] [African Economic Outlook, 2012]). The SMEs are in trade (64 percent), services (15 percent), manufacturing (13.4 percent) and others (8 percent) that include the SMEs in agribusiness sector dealing with products derived from agricultural practices including non-timber forest products (NTFPs).

The increasing focus on the NTFPs is for poverty reduction and bio-diversity conservation (FAO, 1995; Neumann and Hirsch, 2000; Marshall *et al.*, 2006). The NTFPs are described as biological resources of plant and animal origin other than wood derived from forests, other wooded lands and trees outside forests and are used as either food, fibres, medicinal, cosmetic, income generation and/or cultural purposes (Food and Agriculture Organization [FAO], 1995; Marshall *et al*., 2006; Ahenkan and Boon, 2011). The NTFPs are also commonly known as Alternative Forest Products (AFPs), Minor Forest Products (MFPs), Non-Wood Forest Benefits (NWFBs), Non-Wood Goods and Benefits (NWGBs), Non-Wood Goods and Services (NWGSs), Special Forest Products (SFPs), and Secondary Forest Products (Dlamini, 2013). They are more beneficial to forests than logging and make significant contribution to livelihoods (Marshall *et al.*, 2006); generate additional employment and income (Ahenkan and Boon, 2011); and offer opportunities for enterprises (Subedi, 2003). More importantly, the NTFPs support various businesses that help diversify an economy and enhance conservation. The tradable NTFPs targeted by SMEs include fruits, nuts, herbs, flowers, plant dyes, essential oils, woodcrafts, resins, honey, seeds, basketry from reeds, medicinal products and carbon stocks.

The firms utilizing the NTFPs have the potential to achieve dual conservation and development goals by increasing the value of forest resources to local communities thus qualifying them as green businesses. Their contribution is more significant to resource poor people and particularly women and youth by acting as outlets for their products. Although quantification of their contribution is scarce in Kenya, it has been estimated that over two-thirds of Africa's 600 million people rely on these forest products either for subsistence or for cash income (Kaimowitz, 2003; CIFOR, 2005; Sunderlin *et al*., 2005). At global level, they generate US $115.5 to US$117 billion annually (Shanley *et al.*, 2008).

Despite the potential of NTFPs firms, little information exists on them in the country. Few studies have tried to describe and establish what factors influence growth of such firms. Studies conducted on the NTFPs in the country (FAO, 1995; Chikamai and Odera, 2002; Chikamai *et al.*, 2004; Mbuvi and Boon 2008; Chiteva *et al.*, 2016) have concentrated on the ecology, production levels and social capital issues with less focus on entrepreneurship development with NTFPs. Thus, the study was conducted to describe the firms dealing with NTFPs and demonstrate determinants of their growth. As green businesses, NTFPs firm have high potential for income generation and environmental conservation and thus, the study findings would help motivate public and private institutions to invest in them. The findings would also inform policy makers on entrepreneurial dynamics within the NTFPs sub-sector in order to come up with viable policies and development programs.

Materials and methods

A cross-sectional survey covering 314 NTFPs firms were selected using probability sampling methods from nine counties with the highest concentration of NTFP enterprises in Kenya: Garissa (13), Kajiado (13), Kilifi (22), Kitui (25), Kwale (16), Machakos (13), Makueni (16), Mombasa (61) and Nairobi (135). Stratification was applied to establish sampling units; the SMEs in the nine counties were segregated into three mutually exclusive strata/categories based on similarities in sources and use. The three strata were the fruit products, medicinal and bee products; fruit products were fruit related products and included edible fruits, seed oils, gums, seeds and nuts; medicinal were those with medicinal and cosmetic values and included herbs, aloe, resins and essential oils; and bee products included honey, wax, royal jelly and propolis. Sample units were established proportionately by multiplying the sample size with a fraction of firms in each stratum as their number to the total population in sampled counties. The firms in each stratum were numbered sequentially and random numbers used to select firms to interview owners/managers. However, in cases where an oversized firm with over 100 employees or a wrongly categorized one was selected, then it was replaced with the next firm on the list.

A questionnaire with open and closed format questions was administered to entrepreneurs of randomly selected firms. The study achieved a 90 percent response rate with questionnaires from 283 firm having satisfactory responses. However, following data cleaning process, 88 percent, that is 277 questionnaires were found usable and adopted for further analysis. The response rate was the highest (100 percent) in Garissa, Kilifi, Kitui, Kwale and Makueni Counties and least in Nairobi (81 percent). Respondents in Nairobi were skeptical and not willing to participate in the interviews. The busy schedule and fears that disclosures on performance of business would elicit tax payment penalties could have been some of the reasons for unwillingness to provide information.

The data collected was subjected to descriptive and inferential statistical analyses to profile and establish growth determinants of the firms. The profiling using frequency distribution of the scores covered the entrepreneur and firm characteristics of the respondent firms. The characteristics of entrepreneur are many and diverse but this study profiled the entrepreneurs based on age, gender, education, managerial skills, industry experience and social skills which depict knowledge, talents, skills, abilities, experience, intelligence, and training advanced under resource based view (RBV) as some of the resources and capabilities necessary for achieving competitive advantage. Frequency tables were used to show patterns of distribution of the firms by these entrepreneur characteristics. On the other hand, firm characteristics describe those traits which play important role on the growth of the firm and included legal status, nature of products dealing with, level of diversity, age of the firm, average annual profit margins achieved and level of adoption of newer technology. The study tested the null hypothesis that there is no significant influence of entrepreneur characteristics and firm characteristics on growth of firms dealing with NTFPs against alternative hypothesis as a two-tailed test at 95 percent confidence level ($\alpha = 0.05$) that there is significant influence of entrepreneur characteristics and firm characteristics on growth of firms dealing with NTFPs using the following multiple linear regression model:

$$FG = \beta_0 + \beta_1 AE + \beta_2 GE + \beta_3 EE + \beta_4 MS + \beta_5 IE + \beta_6 SS + \beta_7 NP + \beta_8 LS + \beta_9 AF + \varepsilon$$

Where FG is firm growth, AE is age, GE is gender, EE is education, MS is managerial know-how, IE is industry experience, SS is social skills, NP is nature of products, LS is legal status, AF is age of firm and ε is error term. Firm growth was inputted in the model as number of employees in the business organization. The nine entrepreneur and firm characteristics were fitted in the model as individual variables. Respondent firms indicated entrepreneur age as number of years from date of birth. Gender, education, managerial know-how, industry experience, social skills, nature of products, legal status and age of firm were indicated as sex category, highest level of education attained, managerial skills course attendance, years running a business, subscription to social clubs or groups, type of products dealing with, type of business registered and when commenced operations, respectively.

Results and discussion

Characteristics of Non-Timber Forest Products Firms

Profiling of the respondent firms was aimed at providing an understanding of their characteristics. Theoretical perspectives and conceptual arguments show that the operation and achievements of strategic objectives by firms is influenced by individual, organizational, and environmental factors including their years in operation, nature of products dealing with, size and legal status. Therefore, descriptive statistics were performed to provide an understanding of characteristics of the NTFPs firms, including: years of operation; nature and number of products handled; size of the firm; and legal status.

Years in Operation: Firm value is influenced by years of operation since they reflect experience possessed by the firm. Older well developed firms have better experience and out-perform newer firms. Years in operation indicate firm experience and have a positive impact on performance (Kipesha, 2013). Equally, years in operation are a significant determinant of capital structure of a firm as it enhances creditworthiness (Shehu, 2011). Thus, descriptive statistics were performed to derive frequency counts and percentages for profiling the firms in relation to their years of operation captured as the age category reflecting period of time in running the business. Table 1 shows the profile of respondent firms by years in operation.

Table 1. Years in Operation of the enterprises

Operation by the Firm (Years)	Frequency	Percent
0 to 10	163	58.9
11 to 20	77	27.8
Over 20	37	13.4
Total	277	100.00

Majority of firms (58.9 percent) were in operation for a period of not more than 10 years. The least (13.4 percent) were the firms that had been in operation for over 20 years. This implied that, on average firms in the NTFPs sub-sector were relatively new in operation with majority being in existence for not more than 10 years; shorter durations result in lower levels of experience, operation capacity and creditworthiness that negatively affect firm growth.

Nature of Products Handled: The NTFPs are wide and diverse ranging from food products to non-food products including medicinal and essential oils. Nature of the NTFPs has an impact on performance of the business. Studies have demonstrated that firms handling food related products tend to out-perform those dealing with non-food items. Studies (Nils and von der Fehr, 1995; Adegbite *et al.*, 2006) have shown that food processing and distribution businesses are the majority and contribute significantly to satisfying the basic needs in most African countries. Thus, this study performed descriptive statistics to profile the firms based on nature of products dealt with. Table 2 shows frequencies of NTFPs handled by the firms.

Table 2. Nature of Products Handled by enterprises

Type of Product	Frequency Counts	Percent
Fruit products	142	51.3
Medicinal	64	23.1
Bee products	62	22.4
Others	9	3.2
Total	277	100.0

Most of firms handled fruit products (51.3 percent). The firms (3.2 percent) also indicated handling other NTFPs including butterflies, basketry and plant dyes. Fruit products form part of the food products and it was not surprising that most of the firms handled such products. Thus, the firms in the NTFPs sub-sector on average dealt with food related products; food related products tend to have higher demand enabling firms to achieve better performance.

Number of Products Handled: The number of NTFPs handled by the firms was varied. Handling many products hedges a firm against uncertainties in market demand and pricing (Bowen *et al.*, 2009). Highly diversified firms have higher resilience levels and post better performance unlike those that are not. Bowen *et al.* (2009) observed that selling a variety of differentiated products and services helps business perform well. Thus, respondent firms were profiled based on number of products handled using descriptive statistics and results are presented in Table 3.

Table 3. Number of Products Handled by enterprises

Number of Products	Frequency	Percent
One	101	36.5
Two	60	21.7
Three	42	15.2
More than three	74	26.7
Total	277	100.10

The firms handling only one product formed 36.5 percent of the sample size (see Table 3). However, the firms handling more than one product formed over 60 percent. This implied that, on average firms in NTFPs sub-sector were highly diversified; diversification cushions firms against uncertainties in demand for products and pricing.

Size of the Firms: Size of a firm is one of the key determinants of firm growth; the firm size has shown to have an impact on performance due to the advantages and disadvantages faced by the firms with a particular level of performance. According to Chandler (1962), large firms can operate at low costs due to scale and scope of economies advantages. In addition, due to their size of operations, large firms have the advantage of getting access to credit finance for investment, possess a larger pool of qualified human capital and have a greater chance for strategic diversification compared to small firms (Yang and Chen, 2009). Large firms also have superior capabilities in product development and marketing making them have better performance (Teece, 1986). Size of enterprise reflects how large it is in employment terms (Islam *et al.*, 2011). McMahon (2001) found that firm size is significantly linked to better performance. According to Ramsay *et al.* (2005), firm size allows for incremental advantages by enabling a firm to raise barriers of entry to potential entrants as well as gain leverage on economies of scale to attain productivity. Thus, descriptive statistics were performed to establish firm size distribution measured by number of employees as per categorization of firms by the Government of Kenya (GoK). Table 4 shows size distribution of responds firms.

Table 4. Characteristics of the Firms

Size (Employees)	Categorization	Frequency	Percent
Less than 10	Very small	177	64
10 to 49	Small	81	29
50 to 99	Medium	19	7
Total		277	100

There was an inverse relationship between the number and size of the firms. The highest percentage (64 percent) of the firms had less than 10 employees. On the other hand, the least percentage (6.9 percent) of the firms had 50 to 99 employees. This implied that, on average firms in the NTFPs sub-sector were very small according to the categorization by the GoK depicting firms with less than 10 employees as very small enterprises.

Legal Status: Legal status of a firm has an impact on its performance. Stiglitz and Weiss (1981) stated that limited liability businesses have a greater incentive to pursue risky projects and, therefore, expect higher profits and growth rates than other firms. Harhoff *et al.* (1998) in their study of German firms found that firms with limited liability have above average growth rates. Freedman and Godwin (1994) in their study of small businesses in the United Kingdom found that the prime benefit of corporate status was limited liability.

Based on the foregoing, descriptive statistics were performed to establish legal status of the firms. Legal status was measured as categorical data with respondents selecting appropriate choices to depict their status. Table 5 shows distribution of the firms based on their status.

Table 5. Legal Status of the enterprises

Legal Status	Frequency	Percent
Sole proprietorship	143	51.6
Partnership	53	19.1
Limited company	45	16.2
Cooperative society/self-help group	36	13.0
Total	**277**	**100.0**

Most of the respondent firms (51.6 percent) were operated as sole proprietorship ventures (see Table 5. The least number of firms (13 percent) were operated as cooperatives. This demonstrated that, on average firms in the NTFPs sub-sector were operated as sole proprietorships.

Characteristics of Non-Timber Forest Products Firm Entrepreneurs

Although a distinction is sometimes made between the owner and manager based on the motive, status, risk bearing, rewards, innovations and qualifications with owner playing strategic role while the manager playing both strategic and tactical role, the two were considered equally as entrepreneurs of the NTFPs firms. In cases whereby it was not possible to have the owner, then the manager operating the business was listed for characterization. Of the 277 entrepreneurs covered, 68 percent were owners operating their firms as either chairmen (13 percent) or directors (55 percent), 29 percent were managers and a paltry three percent listed others were senior supervisory staff well-versed with the firm and directly involved in decision-making. All these entrepreneurs were characterized using characteristics that depict knowledge, talents, skills, abilities, experience, intelligence, and training in achieving growth: age; gender; education; managerial skills; industry experience; and social skills.

Age of Entrepreneurs: Age was conceptualized as one of the entrepreneur characteristics affecting firm growth. Descriptive statistics were performed to profile the firms by age of entrepreneurs. Age was measured as the entrepreneur’s number of years from date of birth. Table 6 shows the profile of the firms by age of the entrepreneur.

Table 6. Age of Entrepreneurs

Age	Frequency	Percent
Below 30	36	13.0
30 to 49	175	63.2
50 and above	66	23.8
Total	277	100.0

The majority of the firms (63.2 percent) had entrepreneurs in the age bracket of 30 to 49 years. The least percent of the firms had entrepreneurs in the age bracket of below 30 years (13 percent). Therefore, the findings show that on average, majority of entrepreneurs owning/operating firms in the NTFPs sub-sector were young adults as per the classification in Erickson (1956) that a young adult is in the age range of 20 to 40 years, whereas a person in middle adulthood stage is in the age range of 40 to 64 years.

Gender of Entrepreneurs: Gender was conceptualized as one of the entrepreneur characteristics affecting firm growth. Descriptive statistics were performed to profile the respondent firms by gender of the entrepreneurs. Table 7 shows the descriptive statistics depicting profile of the firms by gender of the entrepreneur.

Table 7. Gender of Entrepreneurs

Gender	Frequency	Percent
Male	176	63.5
Female	101	36.5
Total	277	100.0

The majority (63.5 percent) of the firms were operated by male entrepreneurs. This demonstrated that firms in the NTFP sub-sector were dominated by male entrepreneurs.

Education of Entrepreneurs: Level of education was conceptualized as one of the entrepreneur characteristics affecting firm growth. Descriptive statistics were performed to profile the firms by education of entrepreneurs. During data collection, respondent firms indicated their highest levels of education from the four choices: primary, secondary, tertiary (college, vocational school or post-secondary career training) and others (no formal education at all). Table 8 presents the descriptive statistics elucidating profile of the firms by education of entrepreneurs.

Table 8. Education of Entrepreneurs

Education	Frequency	Percent
Primary school	47	17.0
Secondary school	115	41.5
Tertiary level	111	40.1
Others	4	1.4
Total	**277**	**100.0**

Majority of the firms had entrepreneurs with secondary (41.5 percent) and tertiary (40.1 percent) levels of education. The firms that indicated others (four percent) had entrepreneurs who were mostly uneducated. This implied that, on average firms in the NTFPs sub-sector were owned/operated by entrepreneurs with high levels of education.

Managerial Skills of Entrepreneurs: The managerial skills variable was conceptualized as one of the entrepreneur characteristics affecting firm growth. The respondent firms were profiled by the managerial skills of their entrepreneurs. Respondent firms indicated whether their owners/operators had attended managerial training. Managerial skills unlike experience require specialized training to equip one with necessary theoretical and practical managerial capacity; entrepreneurs with managerial skills were those that had attended managerial courses. Table 9 shows profile of the firms by managerial skills of their entrepreneurs.

Table 9. Managerial Skills of Entrepreneurs

Managerial Skills	Frequency	Percent
Attended managerial training	122	44.0
Not attended any managerial training	155	56.0
Total	**277**	**100.0**

The majority of the firms (56 percent) had entrepreneurs who had not attended any training to enhance their managerial know-how. This implied that, on average firms in the NTFPs sub-sector were owned/operated by entrepreneurs with no requisite managerial skills, that is majority of entrepreneurs had not attended necessary trainings for enhancing their managerial skills in running businesses.

Industry Experience of Entrepreneurs: Industry experience was conceptualized as one of the entrepreneur characteristics affecting firm growth. The firms were profiled by the industry experience of the entrepreneurs using descriptive statistics. Respondent firms indicated industry experience of their entrepreneurs as the years involved in managerial position or in running the business. Table 10 shows the frequencies elucidating profile of respondent firms by industry experience possessed by their entrepreneurs.

Table 10. Industry Experience of Entrepreneurs

Industry Experience	Frequency	Percent
0 to10 years	202	72.9
11 to 20 years	46	16.6
Over 20 years	29	10.5
Total	**277**	**100.0**

The majority of the respondent SMEs (72.9 percent) had upto 10 years of experience in running businesses. This implied that, on average firms in the NTFPs sub-sector were owned/operated by entrepreneurs with relatively lower levels of industry experience.

Social Skills of Entrepreneurs: This study conceptualized social skills as one of the entrepreneur characteristics affecting firm growth. The firms were profiled by the social skills of the entrepreneurs using descriptive statistics. Respondent firms indicated whether their entrepreneurs subscribed to social groups/clubs. Social skills unlike managerial skills demonstrate social capital acquired through interactions in collective action; entrepreneurs with social skills were those that were subscribed to groups/clubs. Table 11 shows profile of the firms by entrepreneurs' social skills.

Table 11. Social Skills of Entrepreneurs

Social Skills	Frequency	Percent
Belonging to social groups	113	40.8
Not subscribed to any group	164	59.2
Total	**277**	**100.0**

Majority of the firms (59.2 percent) had entrepreneurs who had not subscribed to any group. This implied that, on average firms in the NTFPs sub-sector were owned/operated by entrepreneurs without necessary social skills

Growth Determinants of Non-Timber Forest Products Firms

Multiple linear regression analysis was performed to establish factors affecting growth of firms dealing with non-timber forest products. The null hypothesis that there is no significant influence of entrepreneur characteristics and firm characteristics on growth of firms dealing with NTFPs against alternative hypothesis as a two-tailed test at 95 percent confidence level (α = 0.05) that there is significant influence of entrepreneur characteristics and firm characteristics on growth of firms dealing with NTFPs. The results of multiple regression analysis are shown in Table 12.

Table 12. Non-Timber Forest Products Firm Growth Determinants

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
	.546	.298	.272	1.115

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	128.602	9	14.289	11.487	.000
Residual	303.512	244	1.244		
Total	432.114	253			

Coefficients					
Model	B	Std. Error	Beta	t-value	p-value
(Constant)	.890	.402		2.213	.028
Nature of products (NP)	.169	.081	.117	2.088	.038
Legal status (LS)	.490	.067	.408	7.265	.000
Age of firm (AF)	.369	.379	.061	.973	.331
Age of entrepreneur (AE)	-.179	.067	-.163	-2.678	.008
Gender of entrepreneur (GE)	.069	.152	.025	.455	.649
Education of entrepreneur (EE)	1.147	.483	.156	2.375	.018
Entrepreneur's managerial skills (MS)	-.040	.168	-.015	-.239	.811
Entrepreneur's industry experience (IE)	.046	.071	.035	.639	.523
Entrepreneur's social skills (SS)	-.132	.152	-.050	-.863	.389

Analysis (N=277) Note: $p \leq 0.05$

From Table 12, the coefficient of determination (R^2) of the nine independent variables (entrepreneur characteristics and firm characteristics) on the growth of firm as dependent variable was 0.298. The adjusted R^2 value was 0.272 and closer to R^2 value implying that 27.2 percent of variance in growth of firms in the population was explained by the model. The exclusion of other characteristics especially the entrepreneur characteristics such as self-confidence, perseverance, desire to be boss, will to succeed, autonomy, innovativeness, risk taking, pro-activeness, and competitive aggressiveness in the model could explain why the R^2 and adjusted R^2 values were not closer to 1 as anticipated. Such low R-squared values are not always bad, and are even expected in studies of this nature. Focus is also put on F-statistic and significance of t-values to account for the influence.

The F statistic (11.487) for the model was statistically significant at five percent significance level ($p \leq 0.05$) and therefore the overall model was significant. Thus, the null hypothesis that there is no significant influence of entrepreneur characteristics and firm characteristics on growth of firms dealing with NTFPs was rejected. It was therefore, observed that entrepreneur characteristics and firm characteristics had significant influence on growth of NTFPs firms.

The calculated t-values for the estimated coefficients of nature of products (2.088), legal status (7.265), age of entrepreneur (2.678) and entrepreneur's level of education (2.375) were significant at five percent significance level ($p \leq 0.05$). Based on the foregoing results of regression analysis, the model fitted with firm growth (FG) as dependent, and firm characteristics (nature of products and legal status) and entrepreneur characteristics (age of entrepreneur and education of entrepreneur) as independents was specified as:

$$FG = 0.890 + 0.169\ NP + 0.49\ LS - 0.0179\ AE + 1.147\ EE$$

$$(0.028) \quad (0.038) \quad (0.000) \quad (0.008) \quad (0.018)$$

Based on the regression equation above, the intercept was 0.890, implying that firm growth would be 0.89 when all the independent variables were zero. Also, a unit change in nature of products would bring about 0.089 change in firm growth, *Ceteris paribus*. Similarly, a change in legal status, age of entrepreneur and entrepreneur's education by one unit each would result in change in firm growth by 0.49, 0.0179 and 1.147, respectively, *Ceteris paribus*.

Discussion of the findings

The characteristics of the NTFPs firms and entrepreneurs identified in the study were similar with observations made in other sectors. Kibas and K'Aol (2004) in their study aimed at investigating and profiling cases of successful Kenyan entrepreneurs opined that most Kenyan entrepreneurs exhibit typical characteristics of other entrepreneurs elsewhere. Bowen *et al.* (2009) in their study on management of business challenges among SMEs in Nairobi observed that training or education was positively related to business success.

The indication of a significant relationship between firm growth, and firm and entrepreneur characteristics was similar with other studies. Studies (Herron and Robinson, 1993; Covin and Slevin, 1997; Chrisman *et al.*, 1999; Islam *et al.*, 2011) proposed a link between characteristics of the entrepreneur and firm growth. Research (Mazzarol *et al.*, 1999; Reynolds *et al.*, 2000; Kristiansen *et al.*, 2003) showed that demographic factors such as age and gender, and individual background including education and previous work experience impact on firm growth. Islam *et al.* (2011) in a study in Bangladesh observed that entrepreneur's age, education, managerial know-how, industry experience and social skills influence firm growth. Therefore, the findings of this study affirm the observation that firm and entrepreneur characteristics have significant effect on the growth of the firm.

Conclusion and recommendations

The objective of this study was to establish the status and growth determinants of the NTFPs firms in Kenya. These firms were very small in size, young, dealt with mostly fruit products and run as sole proprietorships. Their entrepreneurs were young male adults, well-educated but with no requisite managerial and social skills, and low levels of industry experience. It was, thus concluded that entrepreneurship in NTFPs is in nascent stages of growth run with entrepreneurs without requisite qualifications necessary for creating competitiveness and growth. Based on the resource based view (RBV), firm with requisite qualities, resources, strategy are competitive and boast better growth. There is need, therefore for firms to enhance their capacities through appropriate staff recruitment and development policies to enhance their competitiveness and growth.

Acknowledgement

The authors are grateful for the financial assistance and logistical support received from Kenya Forestry Research Institute (KEFRI). Technical guidance received from the School of Business, University of Nairobi is highly appreciated. We wish to thank all those who spared their valuable time to share with us their knowledge on NTFPs firms.

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Management of *Prosopis juliflora* Invasion in Baringo County through Utilization

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Abstract

Desertification in areas surrounding Lake Baringo in the early 1970's prompted introduction of *Prosopis juliflora*. The introduction and subsequent invasion of *Prosopis juliflora* has over the years attracted attention due to its negative impacts. Despite all the misconception surrounding its introduction *Prosopis juliflora* produces a variety of valuable goods and services. The study was conducted in Marigat Sub County in Baringo County to determine the economic contribution of *Prosopis juliflora* enterprises to household incomes and employment. The study involved administration of a structured questionnaire to 63 randomly selected members of the six Charcoal Producers Associations. The data was entered and analysed using SPSS statistical software. Descriptive statistics was used to establish how adoption of Prosopis enterprises is contributing to: reducing invasion, livelihoods and income. Findings indicated that all sampled respondents are involved in Prosopis charcoal production as the major enterprise; while 54 % deal in fencing and construction poles, 54 % pods, 48 % honey, 44 % firewood 41 % and 35 % timber. Income from charcoal were about Ksh 93.7 million in 2016. Earnings per annum from other Prosopis products namely pods, fencing/construction poles and honey totalled Ksh 12.2 million accounting for 12.9 % of the total earnings. Prosopis charcoal market is dominated by brokers. Lack of reliable market (39.3 %), price fluctuation (27.1 %), poor state of roads during rainy season (9.3 %) and exploitation by middlemen were the main challenges experienced in marketing Prosopis products. From the study adoption and utilisation of Prosopis products is contributing significantly to livelihoods and income. However utilization of the species has not reduced its invasiveness.

Keywords: Charcoal, Desertification, livelihoods, invasive species, *Prosopis juliflora*

Introduction

Concerns about deforestation prompted the introduction of Prosopis *juliflora* in the semi-arid areas of Kenya in the 1970's and 1980's (Johansson, 1985). Prosopis *juliflora* is an evergreen tree native to South America, Central America and the Caribbean. It is a hardy nitrogen-fixing tree that is now recognized as one of the world's most invasive alien species. It's fast growth; drought-resistant, evergreen characteristics rendered it an attractive candidate for arid land environmental rehabilitation programmes. *P. Juliflora* has survived in areas where most tree species have failed and however it has become a nuisance (Mwangi and Swallow, 2005). The introduction and subsequent invasion of *P. juliflora* in Lake Baringo area of Kenya has over the years attracted national attention (Maundu, 2009). Despite all the misconception surrounding its introduction *P. juliflora* produces a variety of valuable goods and services including; construction materials, high quality charcoal, soil conservation and rehabilitation of degraded and saline soils (Pasiecznick *et al.,* 2001).

Globally various countries have developed innovative ways of containing the spread and invasion of Prosopis. In India training on management and utilisation of Prosopis was initiated in Jodhpur in 1993 to control the invasion in Rajastan (Muthana and Arora, 1983). Some of the key approaches for Prosopis control in India include utilisation of Prosopis wood as industrial fuel in small scale industries. Fence posts, poles, particle boards and cardboard are also manufactured using wood of *P. Juliflora.* In Sudan the prominent benefit of Prosopis to communities in addition to sand dune fixation includes; wood fuel and charcoal making. Records of commercially produced charcoal and firewood in 1996 from Gash and Atbara rivers were 600,000 sacks and 135,000 m^3 respectively (Elsidig *et al.,* 1998). In Yemen one method devised to reduce Prosopis invasion is ploughing heavily infested areas using tractors (FAO, 2006). In Kenya, to control and reduce the spread of *P. juliflora,* KEFRI in collaboration with various stakeholders have been involved in promoting management through utilisation. Through this approach community have been trained on utilisation of *P. juliflora* as a source of alternative livelihood. The enterprises that have been created through these interventions include; charcoal making, fodder, poles, honey and fuel wood. This study was undertaken to; determine the economic contribution of *Prosopis juliflora* enterprises to household incomes and employment in Baringo County Kenya and establish if adoption of *Prosopis juliflora* enterprises can sustainably act as an effective management strategy for control of Prosopis invasion.

Materials and methods

Study site

The study was carried out in Marigat Sub County, Baringo County. The study site is located in a 900 km^2 area between latitudes 0° 20′ N and 4° 44′ N and Longitudes 35° 57 E′ and 36° 12E′ and has the highest level of *Prosopis juliflora* invasion and colonisation.

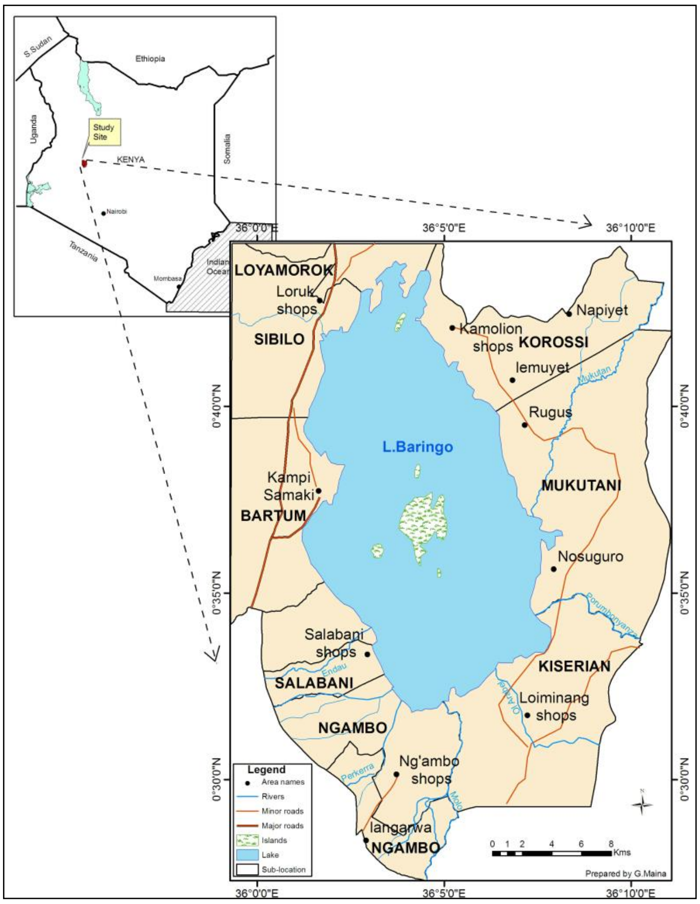

Figure 1. Map showing study sites around Lake Baringo, Kenya

The area falls under the category of marginalized areas in Kenya, with annual mean annual rainfall of 650 mm and temperature range of between 30° C to 35° C. Main economic activities revolve around livestock and honey production. Crop production is practised under irrigation near Lake Baringo. The harsh arid conditions and land degradation prompted the introduction of Prosopis in early 1980's. This study focused on administrative locations of Salabani, Ngambo, Kiserian, Lokisacha, Nalepo and Roteti as they represent areas with high densities of Proposis *juliflora* invasion. In each location all Charcoal Producers Associations (CPA's) dealing in utilisation of Prosopis biomass were selected for the study.

Data collection and analysis

A Multi-stage sampling procedure was used to select the sample for the study. In the first stage, Baringo County was purposively sampled because it is in this region that Prosopis was first introduced in the early 1980's. In the second stage, Marigat Sub County was selected because of the high level of invasion in the areas surrounding Lake Baringo, also there are established groups formed specifically dealing in the extraction and utilisation of Prosopis products. In the third stage, systematic random sampling was applied to choose respondents from the list obtained from the Charcoal Producers Associations (CPA'S) dealing in Prosopis products. A structured questionnaire was administered to 63 randomly selected members of the Charcoal Producers Associations (CPAs) who were involved in the extraction and utilisation of Prosopis. Respondents were drawn from six Charcoal Producers Associations (CPA) namely; Ngambo, Roteti, Nalepo, Kiserian, Salabani and Lokasacha. Data was entered and analysed using SPSS statistical software. Descriptive statistics was used to establish how adoption of the Prosopis enterprises is contributing to reducing invasion, livelihoods and income.

Results

Adoption of Prosopis Enterprises

The study identified six major CPA namely; Ngambo, Roteti, Nalepo, Kiserian, Salabani and Lokasacha which have been formed to collectively exploit and use Prosopis biomass for various uses; charcoal, fencing and construction poles, pods, honey, firewood and timber. Most of the Prosopis raw material is extracted from community land (61.9 %) while 38.1 % was obtained from private land. All the sampled 63 (100 %) respondents were involved in harvesting, processing and sale of Prosopis products. Charcoal production was the most adopted enterprises as cited by 63 respondents (100 %) followed by fencing and construction poles (54 %), pods (48 %), honey 44 %, firewood (41 %) and timber 35 % (Table 1).

Table 1. Prosopis products

Prosopis product	Frequency (n)	Percentage of respondents involved in the enterprise (%)
Charcoal	63	100
Fencing and construction poles	34	54
Pods (for livestock and fodder)	30	48
Honey	28	44
Firewood	26	41
Timber	22	35

Source: Author's analysis of survey data

Economic contribution of *Prosopis juliflora* enterprises to livelihoods

Prosopis *juliflora* produces variety of products. CPA group earnings from charcoal totalled Ksh 93.7 million in 2016 accounting for 87.1 % of the total group earnings. Ngambo CPA earned the highest amount at Ksh 54 million from sales of 132,678 bags of charcoal (Table 2).

Table 2. Charcoal producer association's earnings per annum from Prosopis charcoal sales in 2016

Name of group	Price per unit Ksh (bags)	Quantity sold (Bags)	Income from charcoal per year (Ksh)
Ngambo CPA	407	132,678	54,000,000
Salabani CPA	403	38,114	15,360,000
Roteti CPA	400	28,800	11,520,000
Kiserian CPA	405	18,963	7,680,000
Nalepo CPA	400	6,760	2,704,000
Lokasacha CPA	400	6,240	2,496,000
Total			**93,760,000**

Source: Author's analysis of survey data

Earnings from other Prosopis products namely pods, fencing/construction poles and honey totalled Ksh 12.2 million accounting for 12.9 % of the total earnings from Prosopis products proceeds in 2016. Most of the earnings from other Prosopis products, Ksh 10.8 million came from sale of pods by Ngambo CPA (Table 3). Honey and construction poles sales accounted for the least sales during the period. Timber and firewood are mainly utilised for domestic use and are harvested according to need as there was no high demand for the products.

Table 3. CPA's Earnings per annum from Prosopis fencing poles, honey and pods sales in 2016

Product	Group Sales from prosopis products in Ksh per annum						
	Kiserian	**Lokasacha**	**Nalepo**	**Ngambo**	**Roteti**	**Salabani**	**Total**
Poles	75,000	-	30,000	96,000	-	704,700	905,700
Honey	80,000	84,500	-	16,000	4,000	16,250	200,750
Pods	-	-	-	10,822,000	-	261,200	11,083,200
Total	155,000	84,500	30,000	10,934,000	4,000	982,150	12,189,650

Source: Author's analysis of survey data

Trading in Prosopis products is the major source of income amongst the respondents. Apart from trading in Prosopis products the respondents were involved in crop farming (57 %) and livestock farming (33.3 %). Prosopis enterprises provided employment to household members as harvesting, processing and transportation of Prosopis and its products is done using human labour.

Marketing of Prosopis products

The Prosopis charcoal market is dominated by brokers who account for 100% of the market share. Most of the charcoal is sold to major market outlets in Nairobi, Kisumu, Eldoret and

Nakuru. Fencing poles and pods are bought by local consumers directly. Firewood is mostly bought by consumers (60 %) and wholesalers (40 %). The prevailing market prices for the various prosopis products were determined by market dynamics of demand and supply (82.9 %), seasons (8.6 %), county government regulations (4.3 %), Charcoal Producers Association bargaining power (2.9 %) and distance to raw material (1.4 %). Market demand in key major towns of Nairobi, Kisumu and Eldoret play a significant role in determining the prevailing prices for charcoal with the average farm gate price retailing at Ksh 403 per bag.

Challenges in marketing and utilization of Prosopis products

The main challenges experienced in marketing of Prosopis products include; lack of reliable market (39.3 %), price fluctuation (27.1 %), poor state of roads during rainy season (9.3 %) and exploitation by middlemen (6.5 %) as shown in Table 4.

Table 4. Challenges experienced in marketing prosopis products

Challenges experienced when marketing Prosopis products	Frequency	Percentage
Lack of reliable market	42	39.3
Price fluctuation	29	27.1
Poor roads during rainy season	10	9.3
Exploitation by middlemen	7	6.5
Poor quality charcoal	3	2.8
Flooding	3	2.8
Insecurity	3	2.8
Difficulty in acquiring movement permits	2	1.9
Others	8	7.2
Total	**107**	**100.0**

Challenge experienced during utilisation of Prosopis include; sharp thorns (47.2 %), invasiveness (25.6 %) and loss teeth in goats (20.0 %) when goats feed on the pods (Table 5).

Table 5. Challenges in prosopsis utilisation

Challenges in utilising Prosopis	Frequency	Percentage
Sharp thorns	59	47.2
Invasiveness	32	25.6
Loss of teeth in goats	25	20.0
Tree is difficult to cut down	4	3.2
High carbon emission when producing charcoal	3	2.4
Fast growth along river courses	1	0.8
High coppicing ability	1	0.8
Total	**125**	**100.0**

Discussion

The introduction and subsequent invasion of Prosopis within areas surrounding Lake Baringo have brought mixed results. Despite the negative effects of the plant, through training on utilisation of Prosopis, residents living within these areas have been able to get an alternative source of livelihood apart from livestock and crop farming**.** This findings indicate that the products namely; charcoal, fencing poles, pods, honey and firewood contribute significantly to respondents' livelihoods both at domestic and commercial scale. The survey indicate that charcoal enterprise accounts for the highest share of the sales revenue earned by the six groups. Charcoal prices are determined by season, with prices being high during the rainy season and low during the dry season. During the rainy season demand for charcoal increases due to increase in household demand. Charcoal making and transportation from Prosopis extraction sites is also hampered by heavy rains and poor roads thus reducing supply. The CPAs bargaining power also influences the amount paid for to the group members. The other products; firewood, honey and timber are mainly consumed hence their prices are mainly negotiated by the buyers.

This finding corroborates other studies for example, studies in Malawi studies found that 44% of the people relied on Prosopis as a primary source of income (Chikuni *et al*., 2004). As dry fodder Prosopis pods provide supplementary feed to livestock, and contains about 15% crude sugar and 12% crude protein (Sawal *et al*., 2004) in most parts of Baringo Prosopis has become a major source of dry season feed for goats and sheep. Energy from Prosopis obtained through direct burning and carbonisation are good sources of fuel. In Ethiopia *P.juliflora* is used to produce charcoal sustainably with a well-established market (Kwaschik, 2008; EPP, 2006).

Conclusions

The findings of this research indicate that majority of the respondents have adopted charcoal utilization technology. The technology is contributing significantly to their livelihoods and income. The use of the technology has not reduced the invasiveness of Prosopis. To improve income and livelihoods from the Prosopis enterprise, the study recommends the following; improve market linkages for the products, provide capital for associations, training on business techniques and mechanize harvesting of Prosopis.

Acknowledgement

We are indebted to KEFRI for the financial support in carrying out this study. Dr. Joshua Cheboiwo, Deputy Director, Socio-Economics Policy and Governance for providing financial support for the study. Enumerators who collected the data are also highly acknowledged, finally, we wish to sincerely thank all the farmers who answered our questions through the questionnaires.

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Cost-Benefit Analysis of Agroforestry Technologies in Semi-Arid Regions of West-Pokot County, Kenya

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Abstract
West-Pokot County, Kenya experience harsh arid and semi-arid climatic conditions associated with high poverty indicators (food insecurity, fodder and fuelwood shortages and low household income). To alleviate poverty, Non-Governmental Organizations like Vi Agroforestry initiated projects to promote agroforestry in order to increase sustainable farm forestry management for food and energy security and wealth creation. However, adoption and practice of agroforestry technologies has been slow and low due to scanty information on their profitability in arid and semi-arid regions. Therefore, this study determined the profitability of agroforestry technologies and practices in West-Pokot County. The study determined costs, benefits and benefit-cost ratios (B/C) of agroforestry technologies in West-Pokot. These research outputs enable scaling up of lucrative and sustainable agroforestry. Purposive sampling technique was used to select two sub-locations of the county Lelan and Chepareria. Systematic random sampling technique was used to select 91 and 90 households respectively. Questionnaire based interviews and field observations were used in collecting data. Mann–Whitney U test analysis was used. Boundary tree planting had the highest B/C in Lelan (9.40) and Chepareria (6.88), while scattered trees on farm had the lowest B/C of 0.68 in Lelan and 1.11 in Chepareria. Statistically significant difference in B/C of agroforestry technologies between Chepareria and Lelan, boundary planting and fodder bank technologies having higher B/C in Lelan as compared to Chepareria. In conclusion, all agroforestry technologies, except scattered trees on farms in Lelan were profitable in West-Pokot as they had a B/C greater than1.

Keywords. Agroforestry, Agroforestry technologies, profitability, cost-benefit, ASALs

Introduction

Arid and semi-arid lands (ASALs) experience harsh climatic conditions with low precipitations, high evapotranspiration rates, high temperatures, unreliable rainfalls and periodic droughts (Muneer, 2008; Mabhuye *et al*., 2015). These conditions are threatening survival of human, livestock and crops in the region (Kyule *et al*., 2015). In Kenya, ASALs occupy about 75 % of the national territory, and include parts of West-Pokot County which experience low and unreliable rainfall, ranging from 100 mm to 1200 mm, frequent and high velocity winds, and high temperatures (Mowo *et al*., 2010). These conditions have led to increased food insecurity, reduced fodder availability, fuelwood inaccessibility, soil fertility decline and biodiversity loss (Jama and Zeila, 2005).

To alleviate the problem, non-governmental organizations (NGOs) like Vi Agroforestry are encouraging adoption of environmental friendly and conservation-conscious strategies such as agroforestry to improve survival (Kiptot *et al*., 2007; Nolet *et al*., 2009; Mowo *et al*., 2010). Agroforestry tree leaves and branches help in filtering and absorbing pollutants, and create cooler environments (FAO, 2013). Agroforestry improves farm biodiversity by creating conducive habitats and provision of shelter to a variety of fauna and flora in agricultural farms (Noble and Dirzo, 1997; Pandyey, 2007). Valuable Agroforestry products including food, fodder, timber, domestic wood supply and woodfuel improve households' economic conditions (Batish *et al*., 2008; FAO, 2013).

Paradoxically, farmers have been reluctant in adopting agroforestry practices to address the above challenges (Mandila *et al*., 2015). This may be due to inadequate and scanty documented evidence that benefits accrued from agroforestry technologies may outweigh the costs incurred by farmers in ASALs. This is because most studies on agroforestry profitability have concentrated in high potential areas and neglected the ASALs (Korir, 2002).

The purpose of this study was to determine the profitability of various agroforestry technologies and practices in Semi-arid parts of West-Pokot County in Kenya. The specific objectives of the study were 1). To establish the costs incurred at different stages of agroforestry technology establishment, 2). To estimate the benefits accrued from practising agroforestry, 3). To establish the benefit cost ratio of different agroforestry technologies/ practices. The scientific information generated in this study could be used in developing training manuals to educate framers in ASALs on the cost incurred, the benefits accrued and the most profitable agroforestry technologies/practices. This will help in up-scaling adoption of lucrative agroforestry technologies/practices in conserving the environment and alleviating the negative impacts of hash climatic conditions in ASALs to human livelihood.

Materials and methods

Study area

The study was conducted in Chepareria, and Lelan Sub-locations of West-Pokot County, Kenya. The county lies between 10^0 $10^'$ N and 30^0 $40^'$N, and 34^0 $50^'$E and 35^0 $50^'$E. Mean annual temperatures in Chepareria and Lelan ranges from 10 °C to 30 °C depending on the altitude. Chepareria is less populated, located at relatively lower altitude and drier than Lelan. The main economic activity in Lelan is mixed farming while in Chepareria is agro-pastoralism.

Sampling and sample size

Multi-stage sampling technique was used in this study as Chepareria and Lelan sub-locations were purposively selected based on different economic activities taking place in the two areas. A total of 91 and 90 households were selected in Lelan and Chepareria respectively through systematic random sampling technique, where thereafter every 5th household was included in the sample. The sample size was determined as tabulated by Israel (2012).

Data collection

Data was collected using field observations and questionnaires. Field research assistants were selected with the help of the area sub-chief and trained on different agroforestry technologies/practices, how to conduct field observations and how to sample participants and administer questionnaires. Field observations were used to identify agroforestry technologies practiced and most common tree species in the study sites. Questionnaires were used to collect information on the adopted technologies, the costs and benefits of agroforestry technologies based on willingness to pay by farmers.

Discounting

Discounting of benefits and costs were estimated using equation 1, at 8 % - a lower social discounting rate of environmental projects in developing countries (Asian Development Bank, 2013). A lower discounting rate is recommended by Kenya Wildlife Service *et al.* (2011) for projects with benefits accruing in future especially in natural resources, and has the ability to mitigate against individual and commercial short-sightedness in exploiting natural resources.

$$PV = \sum_{i-1}^{n} Bi / (1 + r)^{n} \quad \text{.......................................} \quad (1)$$

Where: PV = present value, Bi= benefit or cost in year i, n = number of years in the evaluation period, r = real discount rate

Data Analysis

The farmer-level average cost for every activity was computed by adding all the discounted costs incurred by farmers on that particular practice and dividing it by the number of farmers carrying out such activity in their farms (equation 2).

$$Cai = [\sum_{i-1}^{n} Ci] / n \quad \text{.......................................} \quad (2)$$

Where: Cai; Average discounted cost of the i^{th} activity, $\sum_{i=1}^{n} C_i$; Sum of discounted costs attributed to the i^{th} activity, *n*: Number of farmers undertaking the i^{th} activity.

From the individual costs, the total cost of the k^{th} agroforestry technology was calculated by summing up the average discounted costs of individual activities entailed in that technology.
The farmer-level average discounted benefits from every source of income was obtained by adding all the discounted income from every sampled farmer obtained on that particular source and dividing it by the number of farmers obtaining income from such a source (Equation 3)

$$Bai = [\sum_{i-1}^{n} Bi] / n \quad \text{...} \quad (3)$$

Bai ; Average discounted benefits from the i^{th} source

$\sum_{i-1}^{n} Bi$]; The sum of discounted income attributed to the i^{th} source of income by the farmers

n: Number of farmers obtaining income from the i^{th} source

From the individual Benefits, the total benefits (income) of the k^{th} agroforestry technology were calculated by summing up the average discounted benefits of individual sources from k^{th} agroforestry technology (Equation 4).

$$\boldsymbol{Bak = Ba1 + Ba2 + \cdots + Ban} \text{ .... } \textbf{(4)}$$

Bak; Average discounted benefits obtained from k^{th} agroforestry technology

$Ba1, Ba2, Ban$;Average discounted benefits of the 1^{st}, 2^{nd} and n^{th} activities respective

The benefit cost ratio (B/C) was calculated based on equation5, while the average B/C is as indicated in Equation 6.

$$\textbf{B/C} = \frac{\boldsymbol{discounted\ Benefit}}{\boldsymbol{discounted\ Cost}} \text{ .... } \textbf{(5)}$$

$$\text{The average } \textbf{B/C} = \frac{\boldsymbol{\left(\frac{B}{C}\right)1 + \left(\frac{B}{C}\right)2 + \cdots + \left(\frac{B}{C}\right)n}}{\boldsymbol{n}} \text{ .... } \textbf{(6)}$$

$\left(\frac{B}{C}\right)1, \left(\frac{B}{C}\right)2, \left(\frac{B}{C}\right)n$; The 1^{st}, 2^{nd} and n^{th} farmer practicing a particular agroforestry technology like boundary.

Relative costs and relative benefits were computed for various technologies as percentages of the totals.

Mann Whitney U test was used in data analysis.

Results

Costs Analysis at Different Stages of Agroforestry Technology Establishment

Averagely, land preparation, planting materials and damages on other farm components by agroforestry were the costly operations in establishing agroforestry technologies and practices in both Lelan and Chepareria as each account for over 20 % of all costs involved (Tables 1 and 2).

Table 1. Costs at different stages of agroforestry technology establishment in Lelan

		Boundary planting		**woodlot**		**Home-garden**		**Scattered trees**		**Strip planting**		**Fodder bank**		
	Item	Cost KES)	**%**	Cost (Kshs)	**%**	Cost (KES)	**%**	Cost (KES)	**%**	Cost (KES)	**%**	Cost (KES)	**%**	**Mean %**
Tools & Equipments	Hand tools	2,000	**3.9**	2,500	**2.8**	1,500	**4.2**	600	**4.1**	5,000	**9.6**	7,000	**13.8**	**6. 4**
	Total	**2,000**	**3.9**	**2,500**	**2.8**	**1,500**	**4.2**	**600**	**4.1**	**5,000**	**9.6**	**7,000**	**13.8**	**6. 4**
Land preparation	Site Clearing	500	**1.0**	7,400	**8.2**	300	**0.9**	200	**1.4**	3,000	**5.8**	1,400	**2.8**	**3.3**
	Land ploughing	1,200	**2.3**	25,000	**27.6**	13,270	**37.4**	500	**3.4**	6,430	**12.3**	4,300	**8.5**	**15.2**
	Pitting	3,200	**6.2**	8,500	**9. 4**	5,400	**15.2**	320	**2.2**	4,780	**9.2**	3,200	**6.3**	**8.1**
	Totals	**4900**	**9.5**	**40900**	**45.2**	**18970**	**53.5**	**1020**	**7.0**	**14210**	**27.3**	**8900**	**17.6**	**26.6**
Planting materials	Seeds/cuttings/	-	**-**	-	**-**	2,100	**5.9**	-	**-**	1,420	**2.7**	12,400	**24.4**	**5.5**
	Seedlings	11,400	**22.0**	20,900	**23.0**	360	**1.0**	480	**3.3**	8,640	**16.6**	1,560	**3.1**	**11.5**
	Sub-total	**11,400**	**22.0**	**20,900**	**23.0**	**2,460**	**6.9**	**480**	**3.3**	**10,060**	**19.3**	**13,960**	**27. 5**	**17.0**
	Planting costs	1,500	**2.9**	3,200	**3.5**	800	**2.3**	300	**2.0**	3,500	**6.7**	3,700	**7.3**	**4.1**
	Totals	**12,900**	**24.9**	**24,100**	**26. 5**	**3,260**	**9.2**	**780**	**5.3**	**13,560**	**25.7**	**17,660**	**35.3**	**21.7**
Maintenance and	Watering costs	-	**-**	-	**-**	2,000	**5.6**	-	**-**	2,400	**4.6**	-	**-**	**2.1**

management	Weeding	1,000	**1.9**	2,500	**2.8**	1,500	**4.2**	200	**1. 4**	1,680	**3.2**	1,300	**2.6**	**2.3**
	Pesticides	-	**-**	-	**-**	700	**2.0**	-	**-**	500	**1.0**	-	**-**	**0.5**
	Fertilizers/manure	1,500	**2.9**	2,400	**2.6**	1,800	**5.1**	-	**-**	4,200	**8.1**	2,870	**5.7**	**4.1**
	Pruning	300	**0.6**	620	**0.7**	250	**0.7**	450	**3.1**	850	**1.6**	250	**0. 5**	**1.2**
	Totals	**2800**	**5.4**	**5,520**	**6.1**	**6250**	**17.6**	**650**	**4.5**	**9630**	**18. 5**	**4420**	**6.2**	**10.2**
Harvesting Storage	Harvesting	8,000	**15.4**	9,500	**10. 5**	500	**1.4**	-	**-**	1,900	**3.6**	2,300	**4.5**	**5.9**
	Storage	-	**-**	2,500	**2.8**	-	**-**	-	**-**	2,500	**4.8**	2,100	**4.1**	**2.0**
	Transportation	-	**-**	-	**-**	500	**1.4**	-	**-**	1,000	**1.9**	-	**-**	**0.6**
	Totals	**8,000**	**15.4**	**12000**	**13.3**	**1,000**	**2.8**	**-**	**-**	**5,400**	**10.3**	**4,400**	**8.6**	**8.5**
Damage on other components	Damages to crops	13,500	**26.0**	400	**0.4**	2,500	**7.1**	7,000	**47.5**	3,200	**6.1**	2,100	**4.1**	**15.2**
	Other damages	7,800	**15.0**	5,300	**5.8**	2,000	**5.6**	4,680	**31.8**	1,200	**2.30**	6,300	**12.4**	**12.1**
	Totals	**21300**	**41.0**	**5700**	**6.2**	**4500**	**12.8**	**11680**	**79.3**	**4400**	**29.1**	**8400**	**16. 5**	**27.3**
Totals (Ca_k)		**51,900**	**100**	**90,720**	**100.0**	**35,480**	**100.0**	**14,730**	**100**	**52,200**	**100 0**	**50,780**	**100**	**100**

Table 2. Costs at different stages of agroforestry technology establishment in Chepareria

		Boundary planting		**woodlot**		**Home-garden**		**Scattered trees**		**Strip planting**		**Fodder bank**		
	Item	Cost (KES)	**%**	Cost (KES)	**%**	Cost (KES)	**%**	Cost (KES)	**%**	Cost (KES)	**%**	Cost (KES)	**%**	**Mean %**
Tools	Hand tools	1,500	**3.2**	500	**0.7**	700	**2.5**	800	**7.3**	640	**1.3**	560	**1.5**	**2.8**
	Totals	**1,500**	**3.2**	**500**	**0.7**	**700**	**2.5**	**800**	**7.3**	**640**	**1.3**	**560**	**1.5**	**2.8**
Land preparation	Site Clearing	1,000	**2.1**	300	**0.4**	250	**0.9**	-	**-**	4,600	**9. 4**	1,400	**3.8**	**2.8**
	Land ploughing	1,400	**3.0**	16,000	**21.3**	6,430	**23.3**	-	**-**	3,800	**7.7**	2,980	**8.1**	**10.6**
	Pitting	2,200	**4.7**	7,000	**9.3**	3,250	**11.8**	-	**-**	4,780	**9.7**	3,600	**9.8**	**7.6**
	Totals	**4,600**	**9.8**	**23,300**	**31.0**	**9,930**	**36.0**	**-**	**-**	**13,180**	**26.8**	**7,980**	**21.7**	**20.8**
Planting materials	Seeds/cuttings/stems	-	**-**	-	**-**	1,100	**4.0**	-	**-**	2,310	**4.7**	11,050	**30.1**	**6.5**
	Seedlings	10,600	**22.4**	23,100	**30.8**	480	**1.7**	600	**5. 5**	10,900	**22.2**	2,060	**5.6**	**14.7**
	Sub-Total	**10,600**	**22.4**	**23,100**	**30.8**	**1580**	**5.7**	**600**	**5. 5**	**13,210**	**26.9**	**13,110**	**35. 7**	**21.2**
	Planting costs	1,800	**3.8**	2,350	**3.1**	800	**2.9**	760	**6.9**	4,300	**8.8**	3,800	**10. 4**	**5.9**
	Totals	**12, 400**	**26.2**	25,450	**33.9**	**2,380**	**9.6**	**1,360**	**12. 4**	**17,510**	**35.7**	**16,910**	**46.1**	**27.1**

Maintenance and management	Watering costs	-	**-**	-	**-**	3,500	**12.7**	-	**-**	2,400	**4.9**	-	**-**	**2.9**
	Weeding	700	**1.5**	3,400	**4.5**	2,000	**7.2**	-	**-**	2,300	**4.7**	2,000	**5.5**	**3.9**
	Pesticides	-	**-**	-	**-**	300	**1.1**	-	**-**	200	**0.4**	-	**-**	**0.3**
	Fertilizers/manure	2,000	**4.2**	1,200	**1.6**	1,300	**4.7**	-	**-**	4,200	**8.6**	2,870	**7.8**	**4.5**
	Pruning	800	**1.7**	500	**0.7**	600	**2.2**	300	**2.7**	1,070	**2.2**	-	**-**	**1.6**
	Totals	**3,500**	**7. 4**	**5,100**	**6.8**	**7,700**	**27.9**	**300**	**2.7**	**10,170**	**20.8**	**4,870**	**13.3**	**13.2**
Harvesting & storage	Harvesting	5,200	**11.0**	11,200	**14.9**	700	**2.5**	-	**-**	1,000	**2.0**	-	**-**	**5.1**
	Storage	2,000	**4.2**	1,200	**1.6**	-	**-**	-	**-**	2,900	**5.9**	2,100	**5.7**	**2.9**
	Transportation	-	**-**	-	**-**	1,500	**5.4**	-	**-**	600	**1.2**	-	**-**	**1.1**
	Totals	**7,200**	**15.2**	**12, 400**	**16. 5**	**2,200**	**7.9**	**-**	**-**	**4,500**	**9.1**	**2,100**	**5.7**	**9.1**
Damage on other components	Damages to crops	10,280	**21.7**	900	**1.2**	1,200	**4. 4**	4,300	**39.2**	2,100	**4.3**	2,100	**5.7**	**12.8**
	Other damages	7,800	**16.5**	7,400	**9.9**	3,500	**12.7**	4,220	**38.4**	1,000	**2.0**	2,200	**5.6**	**14.2**
	Totals	**18,080**	**38.2**	**8,300**	**11.1**	**4,700**	**17.1**	**8,520**	**77.6**	**3,100**	**6.3**	**4,300**	**11.3**	**27.0**
Totals (Ca$_k$		**47,280**	**100**	**75,050**	**100**	**27,610**	**100**	**10,980**	**100**	**49,100**	**100**	**36,720**	**100**	**100**

Comparative Costs among Agroforestry Technologies/Practices

Woodlot was the most expensive agroforestry technology in Lelan and Chepareria with its costs accounting for 30.7 % and 30.4 % of all total costs incurred in establishing identified agroforestry technologies and practices respectively (Table 3). Scattered tree planting was the least expensive technology both in Chepareria and Lelan with its costs accounting for 5 % and 4.5 % of total costs in Lelan and Chepareria respectively (Table 3).

Table 3. Relative (comparative) costs among agroforestry technologies / practices

Agroforestry Technology/Practice	Lelan %	Chepareria %
Woodlot Technology	30.7	30.4
Strip planting	17.6	19.9
Boundary planting technology	17.5	19.2
Fodder bank technology	17.2	14.9
Home-garden Technology	12.0	11.2
Scattered trees	5.0	4.5
TOTAL	**100**	**100**

Benefits accruing from practising Agroforestry

Although agroforestry benefits in terms of wood, non-timber and environmental services are similar across Lelan and Chepareria sub-locations, they differ in terms of percentages. For instance, woodlot technology dominated by *Cupressus lusitanica* and Eucalyptus species contributes 89.1 % (Table 4) of timber/poles in Lelan which is slightly higher than 88.5 % (Table 5) in Chepareria.

Table 4. Average benefits among agroforestry technologies/practices in Lelan

Item	Boundary planting		Woodlot		Home-garden		Scattered trees		Strip planting		Fodder bank	
	Income (KES)	%	Income (KES)	%	Income (KES)	%	Income (KES)	%	Income (shs)	%	Income (KES)	%
Food products	-	**-**	-	**-**	19,700	**15.2**	-	**-**	31,200	**17.6**	-	**-**
Timber/poles	56,100	**11.5**	248,030	**89.1**	4,100	**3.2**	1,000	**10.0**	-	**-**	-	**-**
Firewood	3,000	**0.6**	2,320	**0.8**	9,760	**7.5**	700	**7.0**	3,150	**1.8**	4,600	**3.0**
Charcoal	4,700	**1.0**	-	**-**	2,500	**1.9**	2,500	**25.0**	-	**-**	1,300	**0.9**
Fruits	-	**-**	-	**-**	17,800	**13.8**	-	**-**	25,420	**14.4**	-	**-**
Fodder	53,210	**10.9**	-	**-**	4,500	**3.5**	-	**-**	6,730	**3.8**	9,520	**6.2**
Medicine	3,200	**0.7**	-	**-**	-	**-**	900	**9.0**	-	**-**	-	**-**
Milk production	14,230	**2.9**	-	**-**	16,700	**12.9**	2,180	**21.8**	8,700	**4.9**	24,900	**16.2**
increased soil fertility	47,920	**9.8**	-	**-**	13,200	**10.2**	-	**-**	24,980	**14.1**	19,420	**12.7**
Weed suppression	21,900	**4.5**	-	**-**	-	**-**	-	**-**	5,420	**3.1**	-	**-**
Improved soil structure	31,200	**6.4**	-	**-**	9,490	**7.3**	-	**-**	15,630	**8.8**	26,520	**17.3**
Soil erosion prevention	26,510	**5.4**	13,100	**4.7**	8,640	**6.7**	960	**9.6**	17,600	**9.9**	14,500	**9.56**
Water purification	23,400	**4.8**	-	**-**	-	**-**	-	**-**	3,410	**1.9**	19,520	**12.7**
Improved aesthetic	1,400	**0.3**	15,080	**5.4**	2,210	**1.7**	1,760	**17.6**	16,770	**9.5**	18,430	**12.0**
Prevention of house damages caused by wind	123,400	**25.3**	-	**-**	6,310	**4.9**	-	**-**	-	**-**	-	**-**

Item	Boundary planting		Woodlot		Home-garden		Scattered trees		Strip planting		Fodder bank	
	Income (KES)	**%**	**Income (KES)**	**%**	**Income (KES)**	**%**	**Income (KES)**	**%**	**Income (shs)**	**%**	**Income (KES)**	**%**
Prevention of crop damages by winds	38,950	**8.0**	-	**-**	6,700	**5.2**	-	**-**	4,800	**2.7**	4,300	**2.8**
Increased farm productivity	38,700	**7.9**	-	**-**	7,840	**6.1**	-	**-**	13,200	**7.5**	10,310	**6.7**
Total (Ba_k)	**487,820**	**100**	**278,530**	**100**	**129,450**	**100**	**10,000**	**100**	**177,010**	**100**	**153,320**	**100**

Table 5. Benefits from agroforestry technologies/practices in Chepareria

Item	Boundary planting		Woodlot		Home-garden		Scattered tree		Strip planting		Fodder bank	
	Income (KES)	**%**	**Income (KES)**	**%**	**Income (KES)**	**%**	**Income (KES)**	**%**	**Income (KES)**	**%**	**Income (KES)**	**%**
Food products	-	**-**	-	**-**	15,870	**17.7**	500	**4.1**	30,680	**23.3**	-	**-**
Timber/poles	43,000	**13.2**	220,200	**88.5**	2,000	**2.2**	2,500	**20.5**	-	**-**	-	**-**
Firewood	4,070	**1.3**	5,690	**2.3**	13,500	**15.0**	1,400	**11.5**	3,780	**2.9**	2,500	**3.0**
Charcoal	3,000	**0.9**	-	**-**	2,000	**2.2**	1,300	**10.7**	2,000	**1.5**	-	**-**
Fruits	-	**-**	-	**-**	12,000	**13.4**	-	**-**	13,740	**10.4**	-	**-**
Fodder	2,560	**0.8**	-	**-**	2,000	**2.2**	-	**-**	3,000	**2.3**	24,600	**29.3**
Medicine	2,000	**0.6**	-	**-**	-	**-**	1,200	**9.8**	-	**-**	-	**-**
Milk production	11,500	**3.5**	-	**-**	8,900	**9.9**	2,100	**17.2**	12,300	**9.3**	9,000	**10.7**
increased soil fertility	60,800	**18.7**	-	**-**	10,700	**11.9**	-	**-**	20,200	**15.3**	7,690	**9.2**
Weed suppression	15,000	**4.6**	2,000	**0.8**	-	**-**	-	**-**	1,000	**0.8**	-	**-**
Improved soil structure	18,830	**5.8**	15,500	**6.2**	3,800	**4.2**	-	**-**	10,100	**7.7**	11,450	**13.7**
Soil erosion prevention	24,700	**7.6**	2,780	**1.1**	7,250	**8.1**	1,200	**9.8**	9,300	**7.1**	7,600	**9.1**
Water purification	14,000	**4.3**	-	**-**	-	**-**	-	**-**	1,200	**0.9**	2,000	**2.4**
Improved aesthetic	2,700	**0.8**	2,600	**1.1**	5,280	**5.9**	2,000	**16.4**	8,690	**6.6**	6,700	**8.0**
Prevention of house damages caused by wind	54,500	**16.8**	-	**-**	2,290	**2.6**	-	**-**	-	**-**	-	**-**
Prevention of crop damages by winds	23,600	**7.3**	-	**-**	2,300	**2.6**	-	**-**	5,670	**4.3**	-	**-**

Item	Boundary planting		Woodlot		Home-garden		Scattered tree		Strip planting		Fodder bank	
	Income (KES)	**%**	**Income (KES)**	**%**	**Income (KES)**	**%**	**Income (KES)**	**%**	**Income (KES)**	**%**	**Income (KES)**	**%**
Increased farm productivity	45,000	**13.8**	-	**-**	2,000	**2.2**	-	**-**	10,090	**7.7**	12,340	**14.7**
Total (Ba_k)	**325,260**	**100**	**248,770**	**100**	**89,890**	**100**	**12,200**	**100**	**131,750**	**100**	**83,880**	**100**

Comparative Benefits among Agroforestry Technologies/Practices

Boundary planting was the most profitable agroforestry technology in Chepareria and Lelan, accounting for over 35 % (Table 6) of accrued benefits from all the identified technologies. However, boundary planting is slightly profitable in Lelan (39.5 %) than in Chepareria (36.5 %). Contrary, the practice of scattered trees on farms is more profitable in Chepareria (1.4 %) than Lelan (0.8 %) (Table 6).

Table 6. Relative (comparative) benefits among agroforestry technologies / practices

Agroforestry Technology/Practice	Lelan %	Chepareria %
Boundary planting technology	39.5	36.5
Woodlot Technology	22.5	27.9
Strip planting	14.3	14.8
Fodder bank technology	12.4	9.4
Home-garden Technology	10.5	10.1
Scattered trees	0.8	1.4
Total	**100**	**100**

Relative Profitability (B/C Ratio) Among Agroforestry Technologies / Practices

Overall, all technologies were profitable with B/C ratio > 1 except for scattered trees on farms dominated by *Albizia lebbeck* and Acacia species in Lelan (0.68) (Table 7). Mann Whitney *U* test indicated that the B/C ratios of agroforestry technologies in Chepareria and Lelan were significantly different (U= 210.500, $P < 0.005$); meaning the presence of significant differences in the profitability of agroforestry technologies in Chepareria and Lelan sub-locations within West-Pokot. Pairwise analysis indicated that profitability of boundary tree planting and fodder banks differed significantly between the two sub-locations (Chepareria and Lelan) as indicated by alphabet letters in Table 7. The two agroforestry technologies were more profitable in Lelan than in Chepareria. However, profitability of home-garden, woodlot, scattered trees, and alley technologies did not vary significantly between the two sub-locations.

Table 7. Relative profitability (B/C ratio) among agroforestry technologies / practices

Agroforestry Technology/Practice	Lelan	Chepareria
Boundary planting technology	9.40[a]	6.88[b]
Home-garden Technology	3.65[a]	3.26[a]
Strip planting	3.39[a]	2.68[a]
woodlot Technology	3.07[a]	3.31[a]
Fodder bank technology	3.02[a]	2.28[b]
Scattered trees	0.68[a]	1.11[a]

Note: B/C ratio values followed by the same letter in rows are not significantly different at 5 % probability level ($p > 0.05$).

In Chepareria, B/C of boundary planting dominated by *Croton megalocarpus* and *Grevillea robusta* was significantly higher than all other technologies and practices (Table 8).

Table 8. Pair-wise analysis of agroforestry technologies B/C in Chepareria sub-location

	Homegarden (3.26 %)	**Woodlot (3.31 %)**	**Scattered trees (1.11 %)**	**Strip planting (2.68 %)**	**Fodder (2.28 %)**
Boundary tree planting (6.88 %)	*	*	*	*	*
Homegarden (3.26 %)		ns	Ns	ns	ns
Woodlot (3.31 %)			Ns	ns	ns
Scattered trees (1.11 %)				ns	ns
Strip planting (2.68 %)					ns

* = significantly different at 5 % probability level , ns = not significantly different at 5 % probability level

In Lelan, while the B/C of boundary planting was significantly higher than all other technologies at 5 % probability level, the B/C of scattered tree planting was significantly lower than other technologies (Table 9).

Table 9. Pair-wise analysis of agroforestry technologies B/C in Lelan sub-location

	Homegarden (3.65 %)	**Woodlot (3.07 %)**	**Scattered trees (0.68 %)**	**Strip planting (3.39 %)**	**Fodder (3.02 %)**
Boundary tree planting (9.40 %)	*	*	*	*	*
Homegarden (3.65 %)		ns	*	ns	*
Woodlot (3.07 %)			*	ns	ns
Scattered trees (0.68 %)				ns	*
Strip planting (3.39 %)					ns

* = significantly different at 5 % probability level, ns = not significantly different at 5 % probability level

Discussions

There are various costs that can be incurred at different stages in establishing an agroforestry technology/practice. The costs can be grouped into purchase of tools and equipments, land preparation costs, purchase of planting materials like seedlings, maintenance costs like weeding, harvesting and storage costs and costs emanating from damages on other farm components by agroforestry components. This concurs with Garrett and Godsey (2008) that undertaking successful agroforestry requires adequate understanding of involved variable and fixed costs. The benefits accrued from agroforestry technologies and practices are many including; food products, environmental services like water purification and protection against strong winds. Therefore, agroforestry can help in land reclamation, carbon sequestration, and secure peoples livelihood especially in the rural areas (Mbow *et al*., 2014). Different agroforestry technologies have different tree arrangement patterns that affect profitability of a technology as it results to difference in tree-crop interface (Noordwijk and Hairiah, 2000). For instance, boundary tree planting where trees are planted at the perimeter of the farm prevents soil erosion, demarcate land and provide protection to crops as well as houses from strong winds (Nolet *et al*., 2009). The ability of boundary planting to shelter houses from destruction by strong winds makes it more profitable in Lelan and Chepareria sub-locations compared to other agroforestry technologies and practices. However, boundary planting is slightly profitable in Lelan compared to Chepareria because Lelan is considered a zone for growing a variety of crops and building permanent houses that require protection from strong winds. Contrary, scattered trees on farm are slightly profitable in Chepareria than Lelan because of higher perceived value of shade provided by scattered trees for herders in Chepareria than Lelan. In Lelan, trees scattered on farms are perceived destructive because they compete with other farm crops like maize for light and nutrients, making it less profitable (Mandila *et al*., 2015).

The profitability of any agroforestry system may be influenced by prevailing environmental conditions like wind velocity, rainfall and terrain, and higher costs of setting up trees, maintaining them and opportunity costs (Nolet *et al*., 2009). For example, strip planting may have lower profitability in areas with average rainfall less than 800 mm (Tengnas, 1994).

Trees in agroforestry systems have both positive and negative interaction based on the management practices, eventually affecting the profitability of the technology. Well-managed trees increase profitability by contributing to increased soil biomass which adds organic matter to the soil, hence improving soil condition and productivity (Batish *et al*., 2008; Ajayi *et al*., 2009; Ehrmann and Ritz, 2014). For instance, the presence of well managed leguminous tree species on farms inform of strip planting aids in increasing soil nitrogen that improves soil fertility, and provide nutritious fodder to dairy cattle (Bekele-Tesemma, 2007). Strip planting technology trees also provide the benefits of weed suppression and soil conservation in terms of erosion control across the slope though the technology was still young. However, poorly managed practices especially scattered trees may compete with food crops for light, hence lowering their potential benefits (Mandila *et al*., 2015). Agroforestry contributes to microclimate amelioration which favored crops and animals within the farm. This is because agroforestry trees provide shade that lower soil surface temperature and reduces evapotranspiration of soil moisture (Tewari, 2008).

Conclusions and Recommendations

Conclusions

Profitability of agroforestry technologies in the semi-arid regions of West-Pokot County based on B/C ranges from 9.40 to 0.68. The ratio depends on the agroforestry technology adopted by the farmer and the main economic activities of the farmer's location. Boundary planting is the most profitable technology/practice because of its major benefit of protecting houses and farm crops from strong wind damages. Scattered tree technology/practice is the least profitable because of its potential cost emanating from its potential to compete with farm crops for light, nutrients and hindrance to farm mechanization. In general, all identified technologies/practices in West-Pokot County have B/C >1 apart from scattered trees on farm.

Recommendation

1). Famers should be trained on agroforestry tree management options like pollarding and pruning that reduces competition for light between trees/shrubs with crops especially on scattered trees on farms to reduce the costs of some agroforestry technologies.

2). Government agencies and NGOs should train famers on how they can access markets for agroforestry products including passion fruits and milk in order to increase their profits.

Acknowledgement

We appreciate the University of Kabianga Research and Extension Committee for financial support.

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Markets and Price Trends for Key Tradable Forest Products in Kenya from 1999 to 2014

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Abstract

Farm forestry in Kenya is an important land use system with vast production and market opportunities. Over the years the industry has grown tremendously boosted by the increasing demand for wood products for industrial and subsistence use. This paper gives an overview of the tree products market in Kenya from 1999 to 2014 with 1999 as the base year. Annual tree products market surveys were conducted by use of a structured questionnaire annually in major market outlets in Kenya namely: Nakuru, Eldoret, Kitale, Kakamega, Kisumu, Busia, Mbale, Bungoma, Nyeri, Nairobi, Meru, Embu, Kitui, Machakos) Mombasa, Kilifi and Malindi). The objective of the survey was to gather data on price trends, demand, supply and market performance of forest industry products. The surveys focused on major tradable forest products namely; charcoal, sawn wood, transmission poles, firewood and construction poles. Analysis of tree products price trends for the last 17 years (1999 to 2014), indicate that prices for most tradable forest products in major market outlets have has been on the upward trend and the country has undergone a major timber supply shock within the last 17 years. This is attributed to a combination of factors ranging from government ban on round wood harvesting in public forests in October 1999, transport costs and permit imposition on harvesting and movement of forest products. Study findings indicate that existence of markets and marketing infrastructure motivate tree growers to specialize in specific commercial forest enterprises

Key words: Tree products, markets, price, forestry products

Introduction

Kenya forest cover has been estimated at 7 % (NFP, 2016) and comprises; public plantations, community, private and small holder farms. The total area is estimated at 9,939,255 hectares which are mostly found in highlandKESs and medium potential eco-zones (MEWNR, 2013). The forest industry plays a significant role in enhancing economic growth and providing alternative income to farmers (Manyara and Jones, 2007). The industry has grown over the years from reliance on public plantations to private sector plantations for sawn wood, poles, and industrial firewood (Cheboiwo, 2016). Kenya, has undergone a major timber supply shortfall within the last 15 years largely due to sawlog harvesting ban in public forests in the region. The decision had a quick impact on aggregate outputs from saw mills as most of them were closed.

This translated into rapid increase in sawnwood prices in most regional markets especially in bulk consuming urban markets of Nairobi and Mombasa (Cheboiwo, 2009). A study by MENR (2013) found that Kenya has a wood supply potential of 31.4 million m^3 against a national demand of 41.7 million m^3. This deficit is brought about by growth in economic sector which rely on wood. An example is the industrial firewood which has witnessed an increased demand with expansion of tea factories managed by Kenya Tea Development Agency (KTDA). The demand for hardwood and softwood timber has also increased over the years. Kenya is now the leading importer of timber from East and Central Africa and manufactured products such as furniture, paper and paper products and wood panels from Asia and Europe (EPZ, 2005). Some of the imported products are re-exported to the regional markets. Tree products on transit through the port of Mombasa mostly are teak beams and charcoal from South Sudan destined for Arabian Peninsula, India and China. Since the lifting of the forest harvesting ban in public forests in 2012 and the collapse of Pan African Paper Mills (PPM) there has been an increase in the number of saw millers accessing saw logs from public forests. The key primary and secondary processing actors in the country include; saw millers, reconstituted wood manufacturers, utility pole manufacturers, charcoal producers, wood carvers, paper and paper product manufacturers, biomass energy producers, and non-timber producers. Pan Africa paper Mills (Pan-Paper) was the only pulp and paper mill in Kenya. Before its collapse in 1999 its demand for wood fibre was about 500,000 cubic meter of round wood which was converted to 120,000 tons of paper annually (MENR, 2007). Sawmilling was a major business with over 450 licensed saw millers and 4 plywood mills before the ban was imposed in 1999. Despite the challenges, the sector continues to play an important role in the economy, for example 70 % of Kenyans use wood fuel either as firewood or charcoal (Githiomi and Oduor, 2012). For domestic use, 2.4 million tons of charcoal and 12.9 million tons of firewood worth. 64 billion are consumed annually (Njenga *et al.*, 2013). Tea tobacco and fish processing companies have an annual consumption of an additional 20 million cubic meters of wood fuel worth KES. 1.6 billion (Ndegwa, 2016). The power transmission pole industry has grown tremendously with the government aiming to supply electricity to 150,000 households. Annual demand for power transmission posts and construction poles is expected to grow from 485,200 to 1.18 million and from 7.23 million to 110.7 million respectively for the year 2005 and 2020 respectively. In 2005, the trade in posts and poles generated over Ksh.12 billion to the economy (Langat, 2015). The wood carving industry supports at least half a million Kenyans both directly and indirectly. The wood carving industry realized an export value of KES. 1.6 billion annually (Obunga, 1995)

Materials and methods

This long term study involved conducting annual market surveys for major tradable forest products; charcoal, sawnwood, transmission poles, firewood and construction poles. The study involved collecting information on commodity flow, changing market niches, and product prices in major market outlets in western Kenya (Nakuru, Eldoret, Kitale, Kakamega, Kisumu, Busia, Mbale and Bungoma), Central (Nyeri and Nairobi), Eastern (Meru, Embu, Kitui and Machakos) and Coast (Mombasa, Kilifi and Malindi) as shown in Figure 1. A structured questionnaire was used to collect market data.

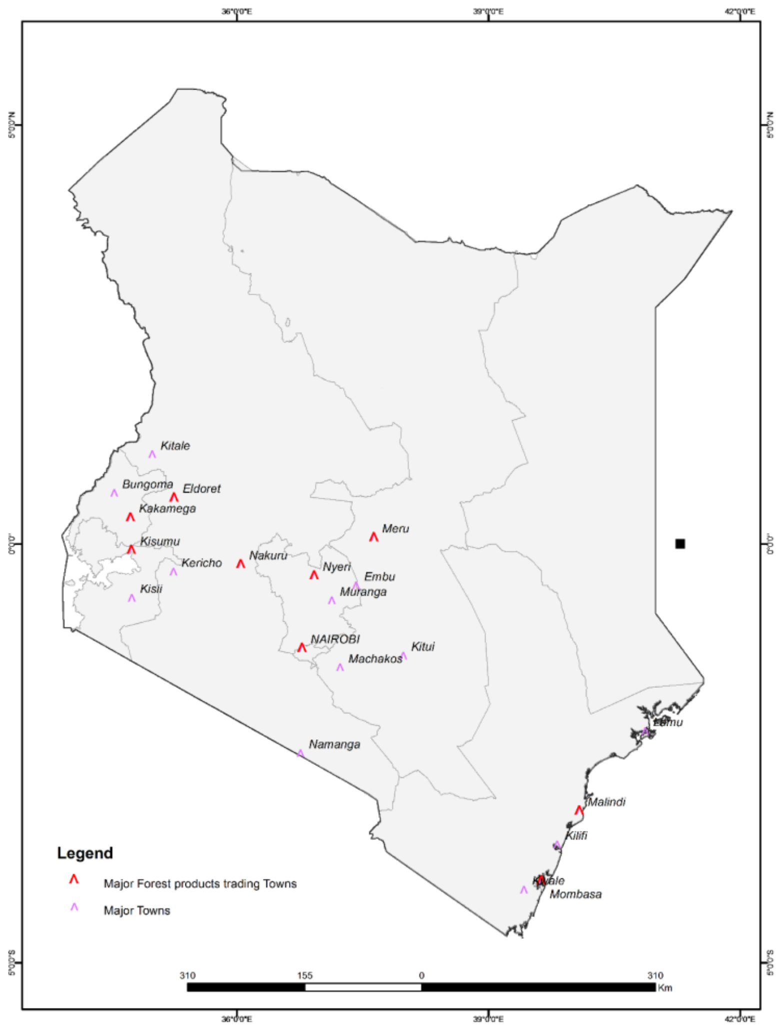

Figure 1. Map showing major timber trading towns

Results

Price trends for timber in major markets

Farm gate Sawnwood (cypress) retail prices rose by over 200 % from an average price of KES 6,350 per m^3 in 2001 to over KES 19,000 per m^3 in 2014 (Figure 2). The prices steady increased over the period in all the major towns with Mombasa and Nairobi recording the highest prices followed by Kisumu and Eldoret. There was a slight drop in sawnwood prices in 2010.

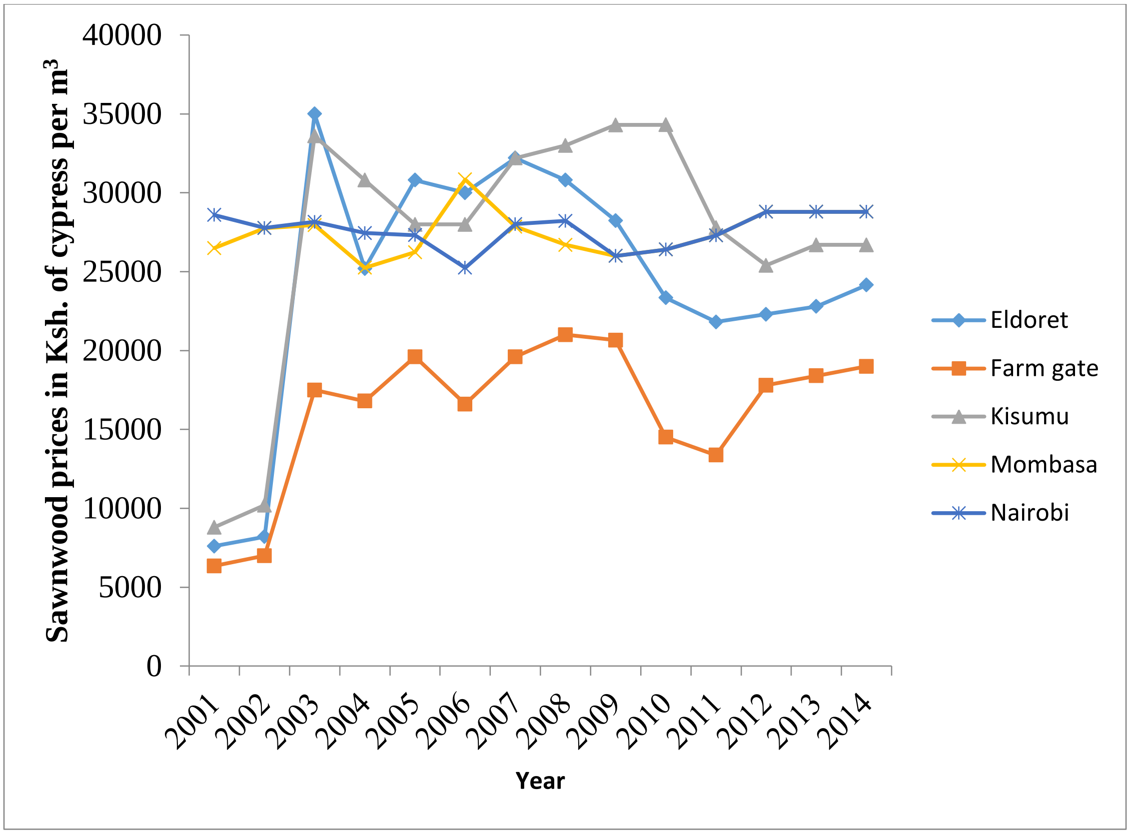

Figure 2. Cypress sawnwood price trends between 2001 and 2014 in major market towns

Price trends of power transmission poles

The farm gate prices of standing poles rose from KES 500 in 1999 to 3,200 per piece by 2014 translating to an increase of 540 %. As shown in Figure 3 the farm gate prices have risen from KES 500 in 1999 to KES 3,200 in 2014 at farm and from KES 1,000 to KES 3,500 per pole on delivery at factory gate in Eldoret depending on the distance, quality and quantity of poles.

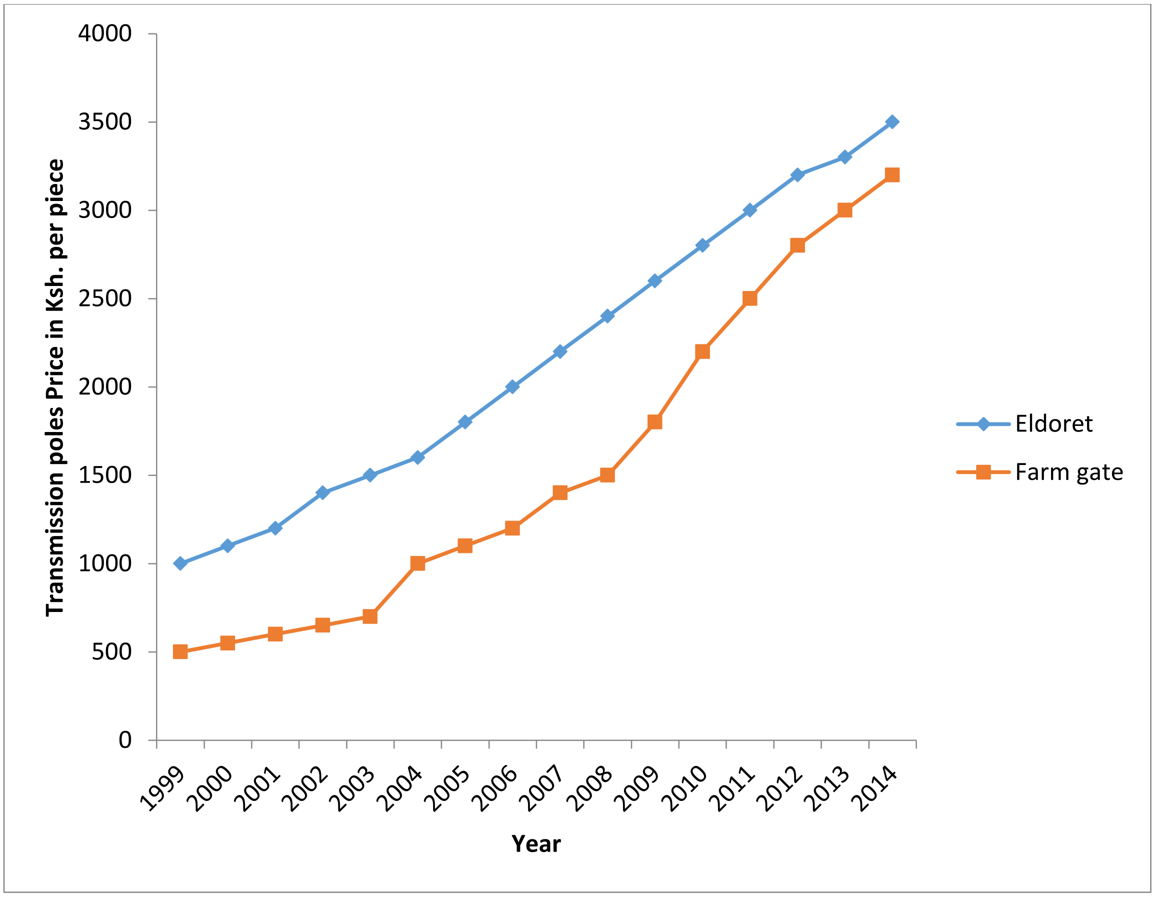

Figure 3. Price trends for transmission poles in western Kenya between 1999 and 2014 years

Charcoal trade

Farm gate prices for charcoal rose from KES 180 in 1999 to KES 700 in 2014. Retail prices in major towns also increased over the period between 1999 and 2014 with prices in Eldoret rising from KES 220 to KES 900 per bag. In Kisumu the prices rose from KES 280 in 1999 to KES 1,200 in 2014. Generally higher prices were realized in Nairobi and Mombasa as compared to Eldoret and Kisumu during the period (Figure 4).

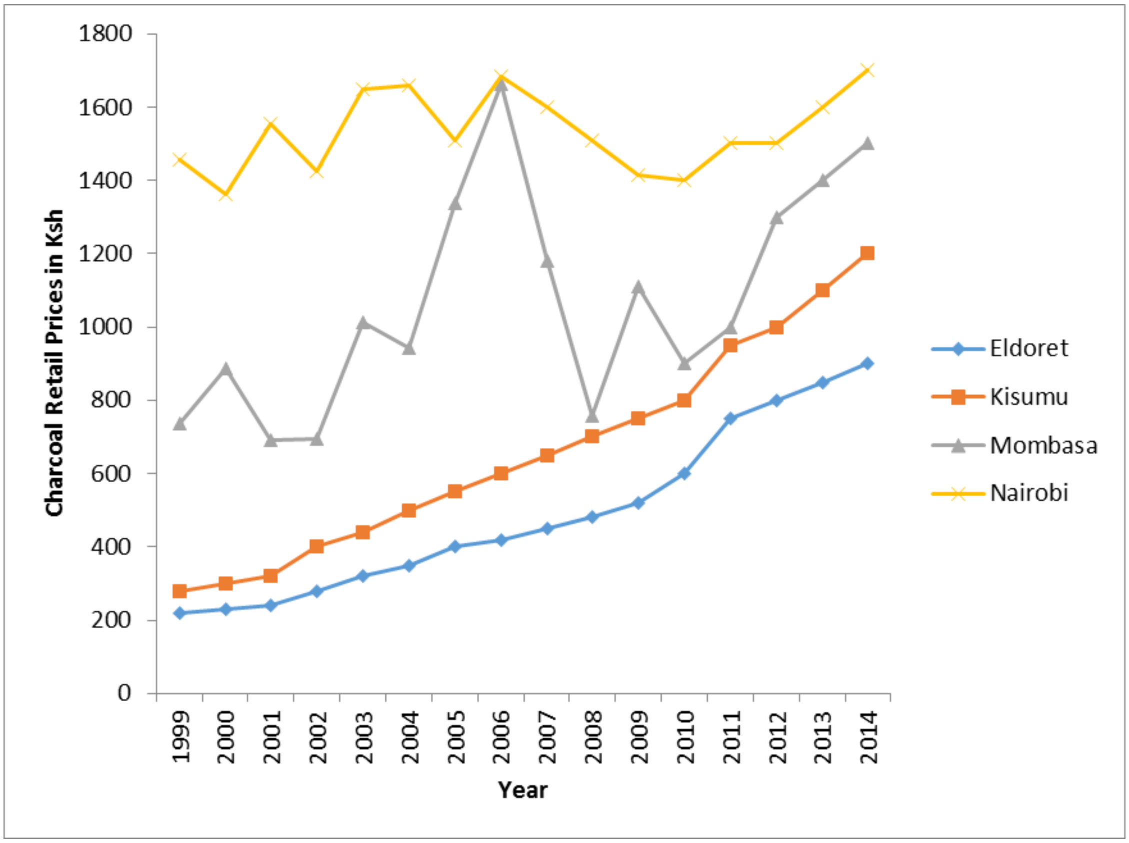

Figure 4. Charcoal farm gate and retail prices change between 1999 and 2014 years in various towns

Price trend for construction poles

Vihiga the main source market for construction poles recorded a steady price rise over the period from a farm gate price of KES 22 in 1999 to KES 85 in 2014 for medium construction post. In Kisumu the main regional market for construction poles retail prices rose from KES 35 to KES 150 in 2014 (Figure 5).

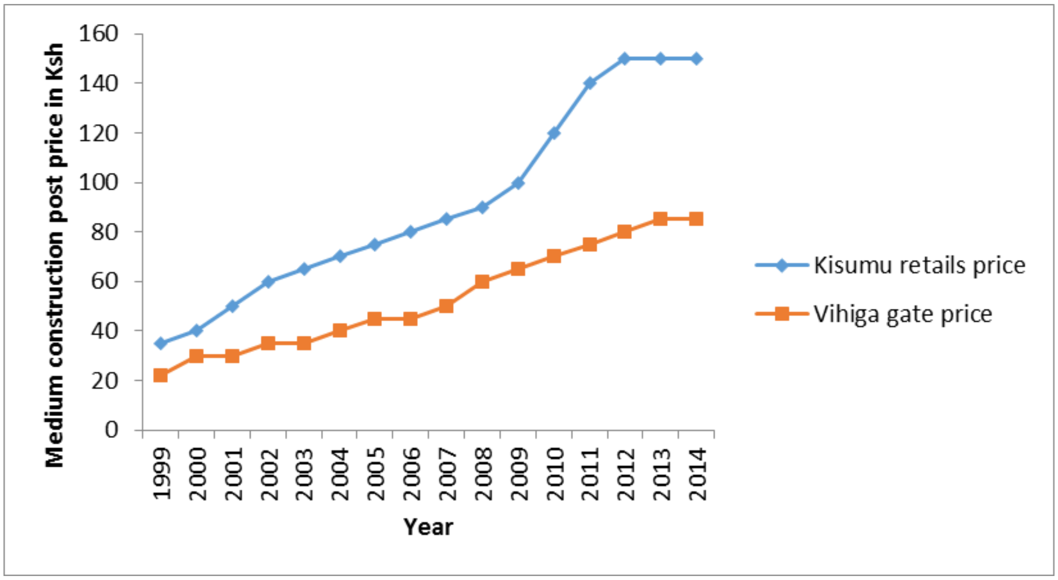

Figure 5. Price trends for Medium construction post between1999 and 2014in Kisumu and Vihiga

Price trends for industrial firewood

Industrial firewood prices rose from farm gate price of from KES 320/ m^3 in 1999 to KES 1650/ m^3 in 2014. Prices offered by KTDA factories rose from KES. 650 per ton in 1999 to KES 2,000 in 2014 for Eucalyptus firewood. Homalime factory prices rose from KES 600 in 1999 to KES 2,550 per tonne in 2014 (Figure 6)

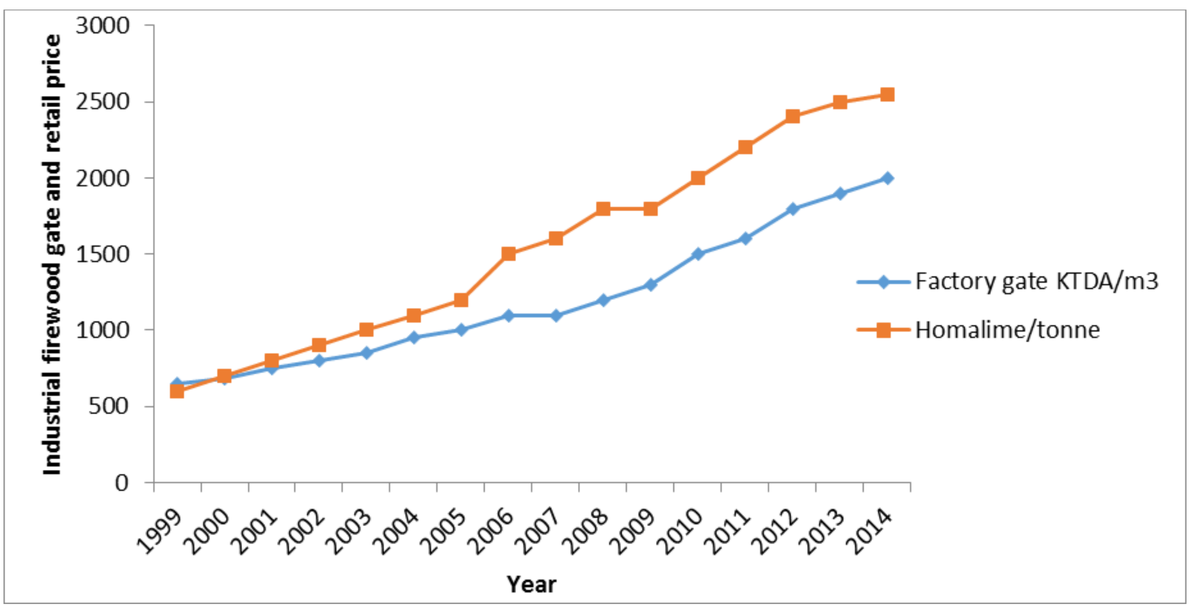

Figure 6. Industrial firewood farm gate and retail price change between 1999 and 2014.

Discussion

Analysis of tree products price trends for the last 15 years (1999 to 2014), indicate that prices for most tradable forest products have been on the upward trend. This is attributed to a combination of factors ranging from government ban on roundwood harvesting in public forests, transport costs, and permit imposition on harvesting and movement of forest products. These challenges have increased transactions costs through time spend in seeking various permits from government offices and numerous inspections by enforcement agencies along the roads to various market outlets. More often the transaction costs are incurred by the tree growers at the upstream and consumers in the downstream to ensure timber traders maintain their profit margins. The study also showed that existence of markets and marketing infrastructure motivates tree growers to specialize in specific commercial forest enterprises. This is attested to; black wattle production for charcoal, power transmission pole production in North Rift, smallholder Eucalyptus polewood production in Vihiga and Kakamega Counties and eucalyptus growing for supplying firewood to KTDA factories. From 1999 to 2002 there was a tremendous increase in sawnwood prices in Kenya attributed to the logging ban imposed in October 1999. However, the continued rise in sawnwood prices was checked in 2003 when imports from Tanzania started to enter Kenyan market. The sawnwood entry had immediate impacts for sawnwood traders from western Kenya who lost their lucrative markets in Nairobi and Mombasa. The entry of Tanzanian softwood sawnwood into Kenya reduced retails prices from an average of KES 25,000 per m^3 to less than 20,000 per m^3 in most outlets in western Kenya. This is because merchants were faced with competition from high quality Tanzanian sawnwood in key market outlets of Mombasa and Nairobi forcing them to divert their merchandise to local markets thus reversing the price upward and stabilizing regional prices. The entry of Tanzanian sawnwood checked the upward trend of prices that was welcomed by consumers (Cheboiwo and Langat, 2004). Timber merchants and farmers were the major losers and were forced to reduce wholesale and retail prices in local market outlets to boost sales. From 2010 there was a decline in sawnwood prices. The decline can be attributed to increased supply of materials from public forests as a result of lifting the 10 year log ban that had been imposed in 1999.

Favorable raw pole prices motivated hundreds of farmers and most tea estates to invest in commercial growing of *E. grandis* and *E. saligna* in many parts of the country mostly in Rift Valley, Central and Western Kenya where climatic conditions favor fast growth and uniformity (Cheboiwo and Langat, 2006). Kenya Power and Lighting Company (KPLC) has been engaging its suppliers and treatment plants to pass on the benefits to commercial tree growers by paying KESs 4,000 ($50) per pole of lengths ranging from 10 to 12 metres. Dwindling land sizes under Blackwattle woodlots on farms in North Rift and the exit of East African Tanning Extract Company (EATEC) translated into increased charcoal prices at farm gate and regional retail outlets from an average of KES 200 in 2009 to KES. 1,200 in 2014. Additionally government ban on harvesting in public forests and restricted tree products movements increased marketing costs mostly in form of bribes, permit related payments, loss of time and other risks that translated into rapid price increase in regional markets despite modest increases in farm gate prices. Increased charcoal prices ensured better returns to black wattle woodlot owners that realized a tripling in price from KES 50,000 to KES 150,000 per hectare of well stocked woodlots. Industrial firewood prices experienced some steady rise due to increased demand for firewood by several industries in the country. The dramatic increase experienced from 2001 was as a result of entry by KTDA affiliated factories and diversion of on-farm trees into high value products such as sawnwood and transmission poles. The price increase was mostly caused by general increases in demand in the construction activities and increase in the number of customers dependent on urban stockists. Trade in construction poles has transformed *Eucalyptus grandis* woodlots into one of the most competitive commercial land based enterprise in the country. Kisumu remains the dominant market for construction poles in the region with Kondele and Nyalenda markets dominating the stock volumes. Most of the construction poles stocked and sold in Kisumu are harvested and transported from Vihiga and Kakamega districts.

Conclusion

The findings of this study indicate that there is growing demand for forest products in Kenya as shown by increasing prices over the years. Kenya stands to benefits if efforts are made to motivate private sector and farmers to invest in commercial forestry ventures. This will ease pressure on local natural forests and provide income opportunities to many farmers and players in the forest industry.

Acknowledgement

We are indebted to KEFRI for the financial support in carrying out this study. We wish to sincerely thank all the players in the forest industry mainly saw millers, timber yard owners, charcoal traders and other relevant government offices who provided information for this survey.

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Financial Assessment of Woodlots on Smallholdings in Coast of Kenya

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Abstract

Little is known about economic viability of woodlots being integrated in smallholder production systems in Coast of Kenya. This study therefore, was conducted as a cross-sectional survey covering a sample size of 219 smallholder farmers in Coast to generate information on economics of woodlots. Farmers were sampled using stratified random sampling procedures and a questionnaire with open and closed ended questions was applied to collect data on costs and benefits. The net present values and annual equivalent values were used in presenting viability of woodlots. *Casuarina equisetifolia* was the most profitable tree enterprise. Production of Casuarina equisetifolia was economically viable and had better financial returns than any other woodlot tree species. Profitability of woodlots on smallholdings depended on level of integration into existing farming systems, market outlets and level of value addition. Highest profitability was achieved when woodlots were intercropped with maize at initial stages of establishment, and their processed products sold through local markets. One acre of *Casuarina equisetifolia* resulted in an average Net Present Value of KES 856,117 that translated to a discounted annual profit margin of KES 153,361 over a seven-year rotation period. The *Melia volkensii* and *Gmelina arborea* woodlots were equally profitable with average net present values of KES 583,486 and KES 514,301, respectively leading to conclusion that woodlots are economically viable on smallholdings in the Coast. It was thus, recommended that smallholders in the Coast be encouraged to integrate high value trees in their farming systems to help diversify and optimize their farm incomes.

Keywords Costs, economics, high value trees, optimize, profitability, smallholder, woodlot

Introduction

The Coast region constitutes about 30 percent of Kenya's land withhuman population of about 17 percent of total Kenyan population. The region is characterized by high levels of inequality with majority classified as poor and food insecure.Over 60 percent of the region's population lives below the poverty line, making it among the poorest in Kenya and experiences highest inequality;the Gini coefficient was highest in Tana River County at 0.62 percent followed by Kwale, Kilifi and Lamu counties by 2015 (KNBS, 2015).Livelihood options are limited with majority of the people depending entirely on subsistence agriculture.

To help address the level of inequality and improve livelihoods of the poor, several development initiatives have been undertaken in the region. One of such initiatives is the Kenya Coastal Development Project (KCDP) funded through World Bank. The primary purpose of the project was to improve sustainable management of natural resources and building the capacity of local communities and institutions to promote growth, livelihood improvement and value addition ((KCDP, 2010)**.** Among the key activitiespromoted with communities were commercial woodlots. The woodlots were established through technical support of Kenya Forestry Research Institute (KEFRI) on selected smallholder farms. The farmers selected for support were those with limited resource base and livelihood options. The established woodlots were aimed at increasing food and cash income levels hence improve living standards of these smallholders.

Studies done elsewhere in Kenyahave demonstrated that communities engage in growing of crops and trees to achieve their economic ends (Jayne *et al.*, 1998; Wekesa *et al*., 2012).Kerkhof (1990) points out that tree production is practised more by resource-poor farmers unable to meet their basic food needs and for whom it is a principal source of farm income. A decision to grow trees is influenced by their low labour and capital input requirements, and their stable income generation compared with food production (World Bank, 1986). Dewees (1993)observed that tree cultivation is an important source of income and land use option for the smallholder. Wekesa *et al.* (2012) observed that it is economically viable to invest in Melia woodlots with leguminous crops intercrop at initial stages and selling the trees as sawn timber in local markets. Thus, KCDP engaged in tree production to address its objective to improve management effectiveness and enhance revenue generation of Kenya’s coastal and marine resources, and provide synergy to multilateral environmental agreements on biodiversity conservation and climate change (KCDP, 2010).By providing alternative sources of income through forestry products, the pressure on natural resources was expected to reduce in the long-term, and contribute to biodiversity conservation. The gains from increased household incomes were aimed at enhancing nutritional status and access to other essential services to Coast region communities.

The establishment of woodlots as an enterprise by local communities was promising with 1,058 farmers planting an average of one acre each through the support of KCDP.Some of the promising trees planted included; *Casuarina equisetifolia, Melia volkensii, Tectona grandis* and *Gmelina arborea*. Over 70 percent (736) of the farmers established C. equisetifolia woodlots with the remainder establishing *M. volkensii* (284), *T. grandis* (7) and *G.arborea* (31) woodlots on their farms.

Despite the efforts of promoting woodlot enterprises as alternative livelihood options, not much information is available on their economic viability when integrated in smallholder production systems. Little is known about their costs and benefits in smallholder production systems where they are being promoted. In addition, there is inadequate information on their optimal biological rotation, merchantable tree volumes per unit area, and their supply and demand dynamics.

Essentially, farmers are not able to make informed decisions whenintegrating woodlots within their farming systems. Therefore, this study was carried out to assess theeconomic viability of woodlots in the region.This involved establishing survival andbiological rotation for the trees in the woodlots, cost components and profit margins in woodlots production.

Materials and methods

The study was conducted as a cross-sectional survey of the woodlots established by farmers supported by KCDP in Kilifi, Kwale and Lamu counties. A representative sample of 293 farms was selected using multi-stage stratified random sampling procedures (Table 1). Initially, the region was classified into administrative counties and those supported to establish woodlots selected. Then the sub-counties and villages with highest number of farms with woodlots were selected.

Table 1. Multi-stage Stratified Random Sampling for Woodlots in Coast

Sampling stage	**Sampling frame**	**Description**	**Site**	**Selected units**		
Stage I	List of all Coast counties	Woodlots establishment through KCDP support	Kilifi	Kwale	Lamu	
Stage II	List of all sub-counties in selected counties	Woodlot establishment through KCDP support	Gaze Malindi Magarini	Msambweni Matuga Kinango	Mpeketoni Witu	
Stage III	List of all villages in selected sub-counties	Woodlot establishment through KCDP support	Ganze	Msambweni	Mpeketoni	
			Matano mane	Maphombe	Bomani	
			Mijomboni	Shimbahills	Witu	
			Gede	Taru	Mitondoni	
			Magarini	Samburu	Soroko	
Stage IV	List of tree woodlots in selected villages	Random selection of farms with woodlots	Casuarina	Gmelina	Melia	Tectona
		Kilifi	114	4	20	-
		Kwale	70	1	24	7
		Lamu	48	2	3	-

The database maintained by KEFRI with 736 farms supported to establish woodlots between 2012 and 2014 was used in selection of farms for data collection because trees planted were well established. All farms in each selected village were numbered sequentially and random numbers used for selection. Information on traders involved in the business of woodlots products was not readily available and snow ball sampling was applied in their selection for interviews. Woodlot farmers gave information on traders who were then requested for the interviews. It was observed that traders dealing with woodlots products were not manyand operated mostly in local trading centers and towns scattered all-over production points. In total 10 traders were interviewed.

Pruduction and trading data of the targeted woodlots tree species were conducted by a team of experts from KEFRI by interviweing smallholders tree farmers using open and closed format questions questionnaire.Additional interviews were conducted with traders dealing with woodlots products in urban /peri-urban trading centres within selected sites. Traders in market centreswere selected among the most experienced in selling products. Equally, a team composed of forestry and GIS expertscollected growth and spatial distribution data.

An analysis was done to establish appropriate biological rotation, merchantable volumesand profitability of the woodlots. Growth data was applied to determine biologicalrotation of *C. equisetifolia*, *G. arborea* and *M. volkensii* using Microsoft Excel. The concept of opportunity cost was used in thequantification of the costs from production data. Cost theoretically is viewed as a measure ofwhat must be given up to get something by way ofproduction or purchase. The value of what must be givenup is considered as the opportunity cost (Nicholson, 1991).Shadow prices for the inputs were applied and apportionedon pro-rata basisto establish fixed costs. The established costs and benefits from data collected were applied in computingNet Present Value (NPV) and Annual Equivalent Value (AEV) using Microsoft Excel to assess profitabilityand thus economic viability of the woodlots. The NPV is the present value of all benefits(revenues) less the present value of costs.Mathematically this is expressed as:

$$\text{NPV} = \sum_{t=1}^{n} \frac{Bt - Ct}{(1+r)t}$$

Where B_t is benefit in each year, C_t is cost in each year, t istime period, n is the biological rotation in years and r is the discountrate.The annual equivalent value (AEV) combines all costs andbenefits into a single sum that is equivalent to all cashflows during an analysis period spread uniformly over thebiological rotation of woodlots. It is an annual payment that would pay off the NPV ofa woodlot over its biological rotation, that is:

$$\text{AEV} = \text{NPV}*\frac{\mathbf{r(1+r)}^{t}}{(1+\text{r})^{\text{t}}-1}$$

The NPV and AEV computations using Microsoft Excel were done for the four common scenarios for the woodlots establishment on smallholdings: intercropped woodlot and sold off as stumpage; intercropped woodlot with trees cut, processed and sold off at local centres as timber; pure woodlot with trees sold off as stumpage; and pure woodlot with trees cut, processed and sold off at local centres as timber. The commonly used intercrop was the maize that was harvested and sold off either at farm gate or local centres.

Results and discussion

Survival and Biological Rotationof Woodlots

The number of surviving trees and yearstakento attain merchantablesizebased on intended use wereused to establishsurvival rates and biological rotation.Results of the computations are elucidated in Table 2. The survival rates and biological rotation in yearswere varied for the target tree species. The survival rates were highest for *G. arborea* (96 percent) and least for *C. equisetifolia* (89 percent). Equally, the biological rotation was highest for *T. grandis* (25 years) and least for *C. equisetifolia* (5 years).

Table 2. Tree Survival Rates and Biological Rotation

Tree Species	Kilifi		Kwale		Lamu		Average	
	Survival Rate (%)	Biological rotation	Survival Rate (%)	Biological rotation	Survival Rate (%)	Biological rotation	Survival Rate (%)	Biological rotation
C. equisetifolia	93	7	85	5	89	4	89	5
M. volkensii	91	12	92	15	89	10	91	12
T. grandis	-	-	100	25	79	25	90	25
G. arborea	100	20	100	20	88	15	96	18

For *C. equisetifolia*, survival rates varied between 85 percent (Kwale) and 93 percent (Kilifi). Equally, biological rotation for *C. equisetifolia* varied between 4 years (Lamu) and 7 years (Kilifi). For *M. volkensii*, the survival rates varied between 89 percent (Lamu) and 92 percent (Kwale) and biological rotation ranging from 10 years (Lamu) and 15 years (Kwale). The *T. grandis* had the survival rates ranging between 79 percent (Lamu) and 100 percent (Kwale) with its biological rotation at 25 years. The *G. arborea* had survival rates between 88 percent (Lamu) and 100 percent (Kilifi and Kwale) with biological rotation ranging from 15 years (Lamu) to 20 years (Kilifi).

Cost Components and Benefits in Woodlots Production

The computations for costs involved in establishment and marketing of woodlot products were done using Microsoft Excel and are presented in Table 3. One acre under a woodlot with value added products sold at local centre required a total investment averaging KES. 511,626 (ranging from KES. 196,347 for *C. equisetifolia* to KES. 670,913 for*T. grandis*) over theirbiological rotation. The key cost components for the woodlots investment were cutting and processing (69.7 percent), land use cost (10 percent), and transport of products to markets (8.1 percent)). The other key costs included weeding (3.6 percent) and pruning (2 percent). However, production of trees only upto stumpage value with no further value addition required an average investment of KES. 113,874 (ranging from KES. 115,497 for *C. equisetifolia* to KES. 123,383 for *T. grandis*) over their biological rotation per acre.

Table 3. Operations and their cost in WoodlotProduction on 1 acre

	Total Cost (KES/acre)									
	C. equisetifolia		*M. volkensii*		*T. grandis*		*G. arborea*		*Average*	
Operation	Cost	%	Cost	%	Cost	%	Cost	%	Cost	%
Land use cost	24,000	12.2	48,000	9.2	73,000	10.9	59,000	9	51,000	10.0
Bush clearing	4,577	2.3	3,700	0.7	2,450	0.4	3,750	0.6	3,619	0.7
Stumps removal	2,367	1.2	2,270	0.4	968	0.1	2,000	0.3	1,901	0.4
Debris removal	171	0.1	1,000	0.2	968	0.1	1,000	0.2	785	0.2
First ploughing	3,021	1.5	4,371	0.8	3,000	0.4	1,000	0.2	2,848	0.6
Staking sticks	596	0.3	273	0.1	465	0.1	444	0.1	445	0.1
Chaining and staking	553	0.3	391	0.1	391	0.1	528	0.1	466	0.1
Pitting	1,113	0.6	886	0.2	460	0.1	889	0.1	837	0.2
Seedlings	8,380	4.3	11,700	2.2	5,000	0.7	2,500	0.4	6,895	1.3
Seedling transport	3,300	1.7	3,000	0.6	3,000	0.4	-	0	3,100	0.6
Seedlings planting	3,564	1.8	2,356	0.4	2,356	0.4	1,667	0.3	2,486	0.5
Security/patrolling	3,611	1.8	3,085	0.6	3,085	0.5	3,611	0.6	3,348	0.7
Watering	9,547	4.9	7,832	1.5	7,832	1.2	1,500	0.2	6,678	1.3
Weeding	28,744	14.6	13,978	2.7	13,978	2.1	17,100	2.6	18,450	3.6
Pruning	19,560	10.0	4,767	0.9	4,767	0.7	11,334	1.7	10,107	2.0
Cutting and processing	39,850	20.3	373,815	71.3	506,250	75.5	506,250	77.3	356,541	69.7
Market transport cost	42,500	21.6	41,280	7.9	41,280	6.2	41,281	6.3	41,585	8.1
Equipment and tools	893	0.5	1236	0.2	1664	0.2	1450	0.2	1,311	0.3
TC (farmgate)	115,497	58.8	108,844	20.8	123,383	18.4	107,773	16.4	113,874	22.3
TC (local centre)	196,347	100.0	523,939	100	670,913	100	655,304	100	511,626	100.0

Among the tree species, cost for cutting and processing trees was highest for *T. grandis* (KES. 506,250) and least for *C. equisetifolia* (KES. 39,850). Land use cost was highest for *T. grandis*(KES. 73,000) and least for *C. equisetifolia* (KES. 24,000). On the other hand, transport of products to markets was highest for *C. equisetifolia* (KES. 42,500) and least for *M. volkensii* (KES. 41,280).

Cutting and processing involved felling and sawing of mature trees into various products. As a practice, felling and sawing of trees was done using chain saws. The key products derived include timber, poles, posts, and saw logs. Others are by-products during timber processing and included off-cuts, sawdust, firewood and leafy parts used as fodder for livestock. The mature trees were split into timber of different sizes depending on their sizes. The derived products were commonly sold in local centres. Others were sold on farm and roadside outlets.

Financial Profitability of Woodlots

Profitability of woodlots on the smallholdings depended on type of woodlot species, whether intercropped, market outlets and whether sold as value added products. The highest profitability was when the woodlot trees were intercropped with maize at initial stages of establishment, cut, processed into timber and sold off in local market centres. From Table 4.*C. equisetifolia* had the highestNPV (KES. 856,117) and AEV (KES. 153,361) when intercropped with maize and its value added products sold in local markets. Under similar scenarios, *T. grandis* had the least NPV (KES. 377,997) and AEV (KES. 29,569). Generally, the least NPV was for *C. equisetifolia* woodlot when produced as pure woodlot and trees sold off as stumpage with NPV of KES. 210,457but had a better AEV of KES.37,701.

Table 4. Profitability of Woodlots in the Coast

NPV/AEV (KES.)	Tree Species			
	C.equisetifolia	*M. volkensii*	*T. grandis*	*G. arborea*
$NPV_{intercrop\ stumpage\ farmgate}$	227,120	271,420	243,447	252,178
$NPV_{intercrop\ timber\ local\ centre}$	856,117	583,486	377,997	514,301
$NPV_{pure\ woodlot\ stumpage\ farmgate}$	210,459	254,759	226,786	235,517
$NPV_{pure\ woodlot\ timber\ local\ centre}$	839,457	566,826	361,336	497,641
$AEV_{intercrop\ stumpage\ farmgate}$	40,685	27,946	19,044	19,727
$AEV_{intercrop\ timber\ local\ centre}$	153,361	60,077	29,569	40,232
$AEV_{pure\ woodlot\ stumpage\ farmgate}$	37,701	26,231	17,741	18,424
$AEV_{pure\ woodlot\ timber\ local\ centre}$	150,376	58,362	28,266	38,929

Discussion of the results

This study provides empirical data in understanding financial viability of establishing woodlot tree species in the Coast of Kenya.The *T. grandis* woodlot was observed to have the highest cost of establishment, and harvesting and processing than other woodlot species at the Coast. The biological rotation of *T. grandis* was lengthy making the cost of investment high especially cost for the use of land. The highest costs were incurred in harvesting and processingdue to high labour and capital inputs. In a study on economic evaluation of *M. volkensii* in the drylands, Wekesa *et al*. (2012) observed that harvesting and processing were the most expensive operations contributing about 85% of the total cost. Generally, costs for the establishing woodlots in the Coast compared favourably with those computed for woodlots elsewhere.

Wekesa *et al*. observed that it required US$ 1,205 to establish one hectare of *M. volkensii* upto to canopy closure i.e. at three to four years of establishment. In Uganda it required US$ 730 per hectare to establish a plantation up to canopy closure by year three with *Pinus caribaea* and 1 to 2 years with *E. grandis* (UIA, 2011). McKean (2004) observed that the costs of establishment and maintenance of the Eucalyptus plantation spread over the first three years in Kwazulu-Natal were R255,400 (US$ 41,938).

Among the target counties, the survival rates were highest for trees in the counties of Kilifi and Kwale. Most of the seedlings planted were sourced from the two counties thus accounting for the high survival rates. The long distances of transport of seedlings from Kilifi to Lamu would have stressed them resulting in lower survival rates. Among the target tree species, the survival rates were highest for G. arborea mostly in Kilifi and Kwale counties. Among these tree species, *G.arborea* and *M. volkensii* were more tolerant to drought. However, M. volkensii was susceptible to waterlogging explaining low survival rates in Lamu where most parts are relatively flat and prone to waterlogging problems. Wekesa *et al*. (2011) observed that apart from environmental conditions, climate and tree types, survival of trees planted on farms was dependent on type of farm enterprise, and availability of water and the farmer.

Profitability of woodlots was better for production systems that intercropped the trees with crops at initial stages, and the sale of the value added tree products.Wekesa *et al*. (2012) observed that the margins were higher in an intercrop possibly as a result of extra benefits derived and complementarity that existed between the tree and other farm enterprises. Wekesa *et al*. also observed that higher profit levels were realized when efforts were made towards processing of the products. Mulatya *et al*.(2002) study indicated thatalthough Melia caused a reduction in the yields of maize, the overall benefits derived were higher than when produced as a monocrop.

Conclusion and recommendations

Tree woodlots are economically viable in the Coast. The tree woodlots established in the Coast hadhigh economic potential that complements their environmental conservation potential in the Coast. The cost/benefit analyzed using NPV and AEV demonstratedthe economicviability of the woodlots intercropped with maize at initial stages and selling of value added tree products in the market. The estimated earnings from the woodlots established were attractive and far above the cost of investment. To help enhancefarmers' profitability and make woodlots more responsive to poverty mitigation and sound environmental management, there was need for intervention strategies that would enable them add value and diversify products through processing, and expand into existing markets with stronger focus on lucrative tourism industry, and penetrate into the non-traditional national and export markets. This would result in increased diversity of products and lead to reduced competition and higher levels of profits to farmers. There is need for support of cottage level wood processing arrangements for the communities in the region to enhance their returns. Formation of producer associations dealing with woodlot tree products be encouraged to help enhance marketing issues. Further research was necessary in establishing yield and growth models for the target woodlot tree species.

Acknowledgement
The authors are grateful for the financial assistance and logistical support received from Kenya Forestry Research Institute (KEFRI) and Kenya Coastal Development Project (KCDP). We wish to thank all those who spared their valuable time to share with us their knowledge on woodlots and their products in the Coast.

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Value of Pollination Services in Farmlands Adjacent to Mau, Cherangany and Mt. Elgon Forests

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Abstract
Pollination plays a vital role in crop yield and quality and by extension food security. Approximately 75 % of global food crops depend on pollination services. Forests are the primary habitats of natural pollinators and communities farming near them benefit from this valuable supporting service. This study estimated the economic value of crop pollination dependency on natural forests within Mau, Cherangany and Mount Elgon Water Towers using the Pollination Value Array Tool developed by Food and Agricultural Organization (FAO). To determine the value of crop pollination on farmlands adjacent to the forests, a buffer zone of 5km between the forest and the farms was developed using GIS. Using the developed maps, a list of pollination dependent crops grown within these zones was identified from the FAO tool. Crop production data were obtained from Ministry of Agriculture in all the counties neighboring the three ecosystems. The crop data gathered include the quantity of crop harvested per season and the producer price in Kshper metric ton. This data was entered into the Pollination value array tool which computes; the Total Economic Value of crop (TVC) and the Economic Value of Insect Pollinators (EVIP) using the Pollination Dependency Ratios (PDR) of the crops. The contributions of natural /insect pollinators to crop production in the Mau, Cherangany and Mt. Elgon were estimated at KES 314 million (12.7 %), 67 million (9.7 %) and 549 million (17.4 %) respectively. The total economic value attributed to insect pollination in the three ecosystems amounted to KES 931 million in 2015.

Keywords: Pollination Services, Crop Production, Pollination Dependence Ratio, Economic Value, Food security

Introduction
Agriculture is the backbone of Kenyan economy accounting for 24 % of the Gross Domestic Product (GDP); it is dominated by smallholder farmers who are engaged in crop and livestock production (Salami *et al*., 2010). The performance of this sector directly affects economic development, food security and poverty alleviation. In recent years, the country has experienced severe food insecurity mainly caused by recurrent droughts. Food security is a priority for the Government with many programs initiated to increase food production. However, over the years efforts have been directed to almost all production inputs except pollination (Mwangi *et al*.,

2012). Pollination is among the building blocks of natural ecosystems which include others soil formation and nutrient cycling. Ecosystem services are benefits (goods and services) that humans derive from the ecosystems (Fisher *et al*., 2009). According to The Economics of Ecosystems and Biodiversity (TEEB) there are four categories of ecosystem services based on their functions namely provisioning, regulatory, cultural, spiritual and supporting. Pollination falls under the supporting service and for many years has not been recognized has an important input in the improvement of crop yields. Pollination is the transfer of pollen from anthers (male part of the flower) to the stigma (female part of the flower) in order for fertilization to take place (Lord and Russell, 2002). Pollination occurs for many flowering plants mainly facilitated by wind, water, gravity and animals. Bees are the most important insect pollinators others are flies, bats, wasps, beetles, birds, butterflies and moths (Maheshwari, 2003).

Pollination services are critically important to human health and wellbeing, due to a large number of crops 75 % that depend on it to produce fruits or seeds (Ingram *et al*., 1996). Globally greater than 90 % of vitamins A and C are derived from pollinator dependent crops (Chaplin *et al*., 2011), and over 35 % of total crop production depend on animal pollinators (Klein *et al*., 2007). Globally pollination services provided by managed bees and those freely provided by wild bees is valued at $ 216 billion per year 9.5 % of annual global crop value (Gallai *et al*., 2009).

Around the world, industrialized countries rely on honey bee (*Apis mellifera*) to provide pollination services to large monoculture farms of pollination dependent crops (Allsopp *et al*., 2008). This is in contrast to least developed countries such as Kenya where smallholder farmers rely on natural wild pollinators and domesticated bees to pollinate a variety of crops grown on farm. In analysing pollination support service, pollination dependency is used as a measure of the level of impact that animal pollination has on the productivity of a particular plant. Pollination dependency is classified into 7 categories namely; essential, great, modest, little, shows an increase to breeding, doesn’t show an increase to breeding and unknown based on the percentage reduction in yield of a particular crop if no pollination service is provided (FAO, 2012). Generally in terms of volume of production 60 % of the global production is not dependent on pollinators, 35 % depend on pollinators while the remaining 5 % is unknown (Sandhu, 2016).

While the services provided by natural pollinators and bees are valuable only few studies measuring the value of pollination services have been undertaken. In United States the value of pollination service provided by wild and honey bees across all the landscapes is estimated at $3.07 billion representing 13.3 % of the total pollination service value (Losey and Mace, 2006). In UK the value of pollination is reported to be US$ 321 million (Carreck and Williams, 1998) and in Australia US$ 1.4 billion (Gordon and Davis, 2003).In developing countries very few studies have been done to assess the value of pollination services to crop production with most focusing on other factors of production (Free, 1999). Studies by Gikungu *et al*., 2006 in

Kakamega forest found out that there is a high density of bee species (243 species), however due to intensification of agricultural activities a deforestation the services provided by the forest is threatened (Biota, 2004). Within the Kenya's major water towers; Mau, Cherangany and Mount Elgon Forest Ecosystems forest adjacent communities practice crop farming with the major pollination dependent crops being crops being tomatoes, beans, cowpeas, soybeans, coffee, pears and plums. The economic value provided by the natural pollinators within these forest ecosystems is very important and underpins the importance of conserving the pollination systems.

Materials and methods

Study sites

This study was undertaken in Mau, Cherangany and Mount Elgon forest ecosystems.

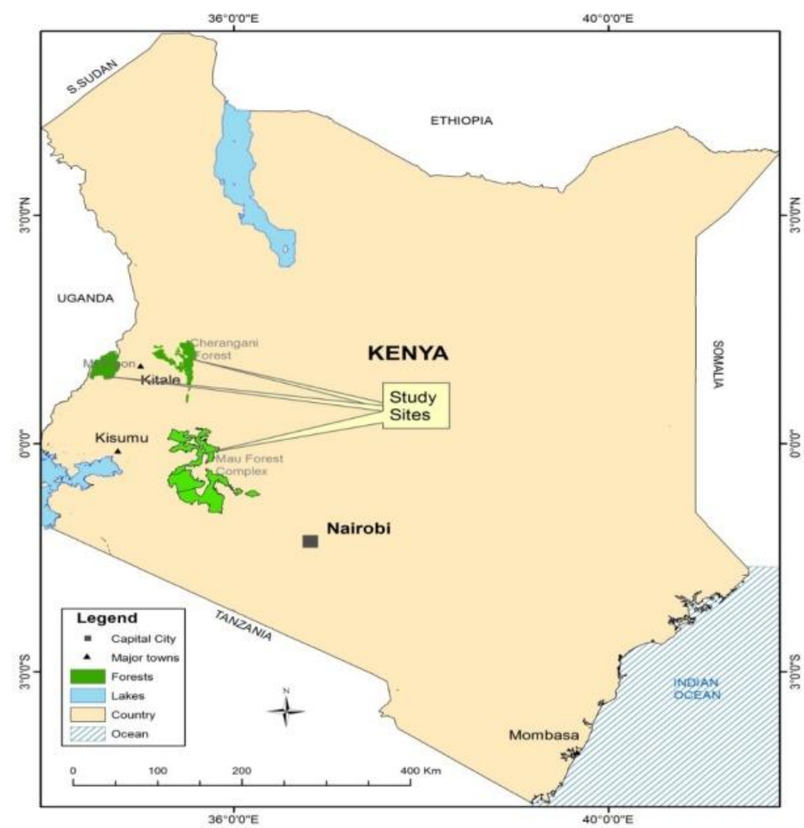

Figure 1. Mau complex, Cherangany Hills, and Mt. Elgon ecosystems in western Kenya

The Mau Forest Complex forms the largest closed-canopy montane forest ecosystem in East Africa, covering approximately 400,000 hectares. It is situated at 0°30' South, 35°20' East within the Rift Valley region and spans seven counties: Baringo, Bomet, Elgeyo Marakwet, Kericho, Nakuru, Nandi, and Narok. The area is thus the largest Water Tower in the region, being the main catchment area for twelve rivers draining into Lake Baringo, Lake Nakuru, Lake

Natron, Lake Turkana, and the trans boundary Lake Victoria (Kipkoech *et al*., 2011; Nabutola, 2010). The Makalia, Nderit, and Njoro rivers support Lake Nakuru ecosystems, including one of the largest bird sanctuaries in the world and an important tourism destination (Langat *et al*., 2016).

The Cherangany forest ecosystem is located within an area defined at 1°16' North 35°26' East. It is comprised of forest reserves totaling 114,416.2 hectares that transverse three counties: Elgeyo Marakwet, with the largest area of public forest at 74,250 hectares; West Pokot at 34,380 hectares; and Trans-Nzoia at 1,551.6 hectares.

The Mt. Elgon ecosystem lies between 0°52' and 01°25'N, and between 34°14' and 34°44'E. It is an extensive transboundary resource between Kenya and Uganda covering 2,223 square kilometers. Of this, 1,078 square kilometers fall on the Kenyan side. The ecosystem covers an area of about 772,300 hectares-made up of 221,401 hectares of protected areas and 550,899 hectares of farmlands and settlements; of which 180,000 hectares of the forest are in Kenya. The forest is an important regional resource that supports local economies through direct and indirect uses. In addition, the ecosystem provides biological, aesthetic, touristic, cultural, educational, employment, resource, and carbon sink values that are significant and could mitigate poverty and the likely negative effects of climate change. The three ecosystems (Figure 1) form upper catchments for the major rivers, which originate as streams and gradually combine to form the rivers that drain into key water bodies. However, the Water Towers face immense challenges, including encroachment, conversion to agricultural land and human settlement, overgrazing, forest fires, and illegal harvesting and growing conflicts (KFS, 2015).

Methodology

The study used the most recent smallholder crop production data for the year 2015 obtained from the Ministry of Agriculture. The data was collected from Bomet, Kericho, Nandi, Uasin-Gishu, Kitale, Bungoma Kericho and Nakuru Counties. The crop data gathered focused on pollination dependent crops based on the FAO tool; key data collected for these crops include annual yield (kg), total area of production (ha) and the annual average farm gate price. To determine the value of crop pollination on farmlands adjacent to the forests in the three ecosystems, a buffer zone of five kilometers between the forest and the farms was developed using geographic information systems (GIS). The crop data from these buffered zones were then entered into the pollination value array tool, which computes the total economic value of crops (TVC) and the economic value of insect pollinators (EVIP) using the pollination dependency ratios (PDR) of the various crops (FAO PIMS).

The pollination dependency ratio on natural pollinators and the contribution of natural pollinators to crop yield in quantity and quality is determined by comparing the yield from naturally pollinated flowers (un-bagged flowers) with those denied pollination (bagged flowers; Kasina *et* *al*., 2007). Pollination Array Tool developed by FAO was used to determine the economic value of crop-pollination dependency.

This can be expressed as:

$$pdr = \frac{Y_{ub} - Y_b}{Y_{ub}} + qcv \ldots\ldots 1$$

Where *pdr* is the pollination dependency ratio of a crop; Y_{ub} is the yield (in kilograms) from un-bagged flowers (with unlimited access by natural pollinators); Y_b is the yield (in kilograms) from bagged flowers (not accessed by natural pollinators); *qvc* is the quality coefficient value representing the value due to a better quality after natural pollination. *Qcv* equals 0.1 if there is quality enhancement or 0.0 if otherwise. $\frac{Y_{ub} - Y_b}{Y_{ub}}$ is the pollination dependency amount, *pda*, which denotes the ratio of the amount of harvestable product (in kilograms) attributable to natural pollinators.

Results

The total area dedicated to crops by farmers living adjacent to the Mau ecosystem in the 2015 was different for each crop. Data for eight crops namely beans, coffee, tomatoes, green grams, avocado, black beans, soybeans and cowpeas were obtained for the ecosystem. Beans had the highest area and economic value while cowpeas had the lowest (Table 1). The contribution of pollination to the income of the farmer depends on the impact it has on the crop yield. Where the impact is high, the change of income is also high. The benefits (in terms of income change) that accrued to the farmers in Mau ecosystem as a result of bee pollination of eight crops was about 12.7 % (KES 314,628,225) of the annual market value of these crops in 2015. In Cherangany ecosystem data for nine crops were obtained namely tomatoes, beans, macadamia, pears, plums, coffee, passion fruit and tree tomatoes (Table 2). Beans had the highest yield and value followed by tomatoes while macadamia nuts had the lowest. The benefits that accrued to the farmers in Cherangany ecosystem as a result of bee pollination of the nine crops is about 9.7 % (67,142,543) of the annual value of these crops in 2015. Mount Elgon ecosystem had the highest number of pollination dependent crops. Data for a total of 17 crops was obtained (Table 3). Beans had the highest yield and value while Bambara Nuts had the lowest. The benefits that accrued to the farmers in Mount Elgon ecosystem as a result of bee pollination of the nine crops is about 17.4 % (548,793,151) of the annual value of these crops in 2015.

Table 2. Pollination (food production and landscape resilience) in Mau ecosystem

Crop	Crop Category	Pollination Dependency Ratio Mean (D)	Dependence Upon Animal Pollination	Producer Price Per Metric Ton (KES)	Total Economic Value of Crop (KES)	Economic Value of Insect Pollinators (KES)	Consumer Surplus Loss CSL With Elasticity (KES)	
							- 0.8	**- 1.2**
Beans (dry)	Pulse	0.05	Little	48,487	1,429,542,221	71,477,111	73,703,332.28	72,951,099.98
Coffee	Stimulant Crops	0.25	Modest	90,000	866,430,000	216,607,500	256,566,563	242,221,287.9
Tomatoes	Vegetables	0.05	Little	22,500	88,425,000	4,421,250	4,558,953.951	4,512,424.272
Green Grams	Pulse	0.05	Little	29,993	65,924,614	3,296,231	3,398,894.877	3,364,205.013
Avocados	Fruits	0.65	Great	30,000	28,860,000	18,759,000	33,713,411.09	27,328,532.11
Black Beans	Pulse	0.05	Little	55,000	550,000	27,500	28,356.51312	28,067.10036
Soybeans	Oil Crops	0.25	Modest	22,222	133,332	33,333	39,482.16587	37,274.61972
Cowpeas	Vegetables	0.05	Little	31,500	126,000	6,300	6,496.21937	6,429.917537
Total					**2,479,991,167**	**314,628,225**		

Table 2. Pollination (food production and landscape resilience) in Cherangany ecosystem

Crop	Crop Category	Pollination Dependency Ratio Mean (D)	Dependence Upon Animal Pollination	Producer Price Per Metric Ton (KES)	Total Economic Value of Crop (KES)	Economic Value of Insect Pollinators (KES)	Consumer Surplus Loss CSL With Elasticity (KES) - 0.8	- 1.2
Beans (dry)	Pulse	0.05	Little	51,763	483,880,524	24,194,026	24,947,572	24,692,951
Tomatoes	Vegetables	0.05	Little	40,194	13,4247,960	6,712,398	6,921,462	6,850,820
Coffee	Stimulant Crops	0.25	Modest	100,000	50,000,000	12,500,000	14,805,960	13,978,122
Tree Tomatoes	Fruits	0.95	Essential	83,333	12,499,950	11,874,953	51285058	28,169,870
Passion Fruit	Fruits	0.95	Essential	49,697	8,696,975	8,262,126	35682132	19,599,491
Avocados	Fruits	0.65	Great	22,500	3,510,000	2,281,500	4,100,280	3,323,740
Plums	Fruits	0.65	Great	76,000	1,155,200	750,880	1,349,471	1,093,899
Pears	Fruits	0.65	Great	65,374	849,862	552,410	992,784	804,764
Macadamia Nuts	Tree Nuts	0.95	Essential	25,000	15,000	14,250	61,542	33,804
Total					**694,855,471**	**67,142,543**		

Table 3. Pollination (food production and landscape resilience) in Mt. Elgon ecosystem

Crop	Crop Category	Pollination Dependency Ratio Mean (D)	Dependence Upon Animal Pollination	Producer Price Per Metric Ton (KES)	Total Economic Value of Crop (KES)	Economic Value of Insect Pollinators (KES)	Consumer Surplus Loss CSL With Elasticity (KES)	
							- 0.8	**- 1.2**
Beans (dry)	Pulse	0.05	Little	44,444	1,312,431,320	65,621,566	67,665,411	66,974,803
Coffee	Stimulant	0.25	Modest	86,000	1,213,460,000	303,365,000	359,328,811	339,237,843
Tomatoes	Vegetables	0.05	Little	24463	211,433,709	10,571,685	10900950	10789693
Avocados	Fruits	0.65	Great	28,811	107,551,463	69,908,451	125,638,485	101,844,200
Sunflower Seeds	Oil Crops	0.25	Modest	30,000	76,530,000	19,132,500	22,662,003	21,394,914
Mangoes	Fruits	0.65	Great	20,234	58,739,302	38,180,546	68,617,541	55,622,276
Green Grams	Pulse	0.05	Little	66,666	33,719,663	1,685,983	1,738,494	1,720,751
Papaya	Fruits	0.05	Little	46,433	33,060,296	1,653,015	1,704,499	1,687,103
Pumpkins	Vegetables	0.95	Essential	38,468	27,119,940	25,763,943	111,268,260	61,117,460
Groundnuts	Oil Crops	0.05	Little	86,363	25,217,996	1,260,900	1,300,172	1,286,902
Soybean	Oil Crops	0.25	Modest	50,000	17,250,000	4,312,500	5,108,056	4, 822,452
Cowpeas	Vegetables	0.05	Little	26,563	16,575,312	828,766	854,578	845,856
Macadamia	Tree Nuts	0.95	Essential	33,892	6,575,048	62,46,296	26,976,245	14,817,519
Watermelon	Vegetables	0.95	Essential	33,892	6,575,048	6,246,296	26,976,245	14,817,519
Oranges	Fruits	0.05	Little	40,000	4000,000	200,000	206,229	204,124
Lemons	Fruits	0.05	Little	42,857	899,997	50,000	46,401	45,928
Bambara Nuts	Vegetables	0.05	Little	80,000	240,000	12,000	12,374	12,248
Total					**3,151,379,094**	**548,793,151**		

Discussion

Pollination plays a vital role in crop yield, quality, and, by extension, food security as exhibited by the results .The percentage contribution of pollination to total crops yield was on average 13.3 % which is quite substantial. Given that approximately 75 percent of global food crops depend on pollination services (Kasina and Kitui, 2007) this service cannot be underestimated. With forests ecosystems being the primary habitats of natural pollinators' communities farming near them benefit from this valuable supporting service. Farms adjacent to complex and bio diverse landscapes also experience lower pest pressure due to natural enemy populations supported by forest habitats (Bianchi *et al*., 2006). The contributions of natural and insect pollinators to crop production in farmlands adjacent to Mau, Cherangany, and Mt. Elgon is estimated at Ksh 930 million in 2015 (Tables 1,2 and 3). Mount Elgon had the highest value of insect pollination at Ksh 549 million followed by Mau at Ksh 314 million and Cherangany Ksh 67 million and respectively. Generally the pollination in Kenya is a public good and is not managed in anyway unlike other countries, where it is managed and to some extent traded. Therefore the amounts calculated represent the value of feral pollination obtained by smallholder farmers living adjacent to these ecosystems. Although most farmers have little knowledge on the role of these pollinators, their farming activities can positively or negatively affect the presence of pollinators within the farms. This study compares well with other studies e.g Kasina *et al.,* 2007 who determined the economic importance of pollination in crop production in Kakamega, Western Kenya, the difference is that this study was broader and focused on all pollinators. There is need to develop policies that encourage the conservation of natural pollinators given the empirical evidence of the magnitude of influence natural pollinators have on crop yields.

Conclusions

This study attempted to estimate the monetary value contributed by natural pollinators in farmlands adjacent to Mau, Cherangany and Mount Elgon forests. The results show that the highest net economic benefit of natural pollinators was gained from beans, coffee and tomatoes. In terms of the ecosystems Mount Elgon had the highest percentage contribution of pollination to total crops yield at 17.4 % followed by Mau, 12.7 % and Cherangany, 9.7 %. On average more than 13.3 % of the net benefit gained by farmers for the selected crops was as a result of natural pollination. The measured economic value shows that pollination impacts of farmer's wellbeing. Therefore, efforts and policies should be put in place to manage pollination within the ecosystems through the promotion of good agricultural practices and conservation measures.

Acknowledgement

We thank our partner agencies and organizations (KFS, KWS, WRMA, WSB, WSP, KWTA) and County Departments of Agriculture (Nakuru, Bomet, Kericho, Bungoma, Trans-Nzoia, Elgeyo Marakwet, West Pokot, and Uasin Gishu) for providing the data used in this assessment. We acknowledge the Center for International Forestry Research (CIFOR) in Nairobi for facilitating and coordinating activities related to this work. We also extend our sincere gratitude to the United States Agency for International Development (USAID) for funding this work and to the US Forest Service (USFS)-International Programs for the technical support to undertake this work. We highly acknowledge the technical guidance provided by professional peers and specialists in various fields, not named here, but whose expert opinions informed this study.

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The Value of Forest Ecosystem Services of Mau Complex, Cherangany and Mt. Elgon, Kenya

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Abstract
The ecosystem services from Kenya's forest ecosystems have remained largely unmeasured and undervalued. Consequently, the benefits they provide are ignored in most forest management, investment decisions and this has led to degradation and conversion to alternative uses. This study was undertaken to value ecosystem services provided by Mau, Cherangany hills and Mt. Elgon forest ecosystems. Primary data was collected from 1206 households, 148 forest product industry players using structured and semi- structured interviews. Secondary information was obtained from Kenya Forest Service (KFS), Kenya Wildlife Service (KWS), Water Resources Management Authority (WRMA), Water Service Boards (WSB) and Water Service Providers (WSP). Additional data were obtained from published, unpublished sources and from discussions with experts. Market *prices, Contingent valuation, Cost-based and Benefit Transfer (BT) techniques were applied in estimating total economic values.* Total Economic Value of the three ecosystems is about 339 billion (US$ 3.4 billion) per annum with Mau, Cherangany and Mt. Elgon ecosystems contributing KES 184 billion (US$ 1.84 billion), KES 42billion (US$ 420million) and KES 115billlion (US$1.15billion) respectively. In all the three Water Towers, regulating services contributed the bulk of Total Economic Value (TEV) with 84 %, 66 % and 93 % respectively underscoring the importance of indirect use values in forest ecosystems. Mau Forest ecosystem had the highest regulation value of KES 162 billion followed by Mt. Elgon with KES 109 billion per annum and Cherangany at KES 30.6 billion per annum. Provisioning services contributed to 10.0 %, 22.7 % and 4.0 % of TEV for Mau, Cherangany and Mt. Elgon respectively. The TEV estimate from this study is very conservative because it did not encompass of all ecosystem service values. However, this study has provided vital statistics on the magnitude of ecosystem services that can assist conservation and management of the three water towers for enhanced livelihood and flow of ecosystem services.

Keywords Total Economic Value, Ecosystem services, provisioning, regulating, supporting, cultural and educational services

Introduction

Forests cover about 25 % of the world's land mass and are critical in provisioning of various commodities and services such as water, food, medicine, fuel wood, fodder and timber. Forests also provide a wide range of environmental services that support biodiversity conservation, watershed protection, protection of soil and mitigate global climate change (Landell-Mills and Porras, 2002). However, there is unprecedented increase in deforestation globally. According to the Food and Agriculture Organization (FAO), about 13 million hectares of global forests are cut down and converted to other land uses every year (FAO, 2006). In the period 1990 to 2000, the world lost about 3 % of its forest cover to alternative land uses (UNEP *et al*., 2009). This raises serious concerns about the sustainability of the various ecosystem services provided by the forest ecosystems.

Forest resources in Kenya contribute significantly to the natural resource-based economic production and consumption activities. The direct forest use and indirect use values contribute 1 % and 13 % to GDP respectively (World Bank, 2000, UNEP, 2012). Mau Forest Complex (MFC), Cherangany and Mt. Elgon are among five major Water Towers in Kenya. These forest ecosystems support important functions, which provide critical ecosystem services and goods such as hydrological services, climate regulation, and maintenance of natural cycles, conservation of biological diversity, maintenance of soil fertility, and wood and non-wood products. Most ecosystem services are not reflected in market decisions by individuals i.e. markets fail to reflect the benefits of non-market ecosystem services due to lack of information about their contribution to human welfare (Nahuelhual *et al.*, 2007, TEEB, 2010, Emerton, 2014, Langat, 2016).

Forest use decisions that ignore these non-market benefits of forest ecosystems result in suboptimal resource allocation leading to detrimental environmental consequences (Pearce, 1989, TEEB, 2010, UNEP, 2012). These Water Towers face significant losses due human activities and conversion to alternative land uses. For example, in 2001, East Mau lost about 50 % of its original size to human settlement (UNEP *et al.*, 2006). Worldwide, quantifying the value of ecosystem services has become a critical tool in development of sustainable management of ecosystem services (MEA, 2005, TEEB, 2010, De Groot *et al*., 2012,). However, in Kenya knowledge on the magnitude and value of forest ecosystems services is still limited and consequently most policy decisions on management and conservation have often disregarded important ecosystem values. This study provides estimates of TEV of ecosystem services that can assist in development of sustainable management of the three Water Towers for enhanced ecosystem services at different scales -locally, nationally, regionally and globally.

Research methodology

Study sites

General description of the study areas

The three ecosystems (Figure 1) form upper catchments for the major rivers, which originate as streams and gradually combine to form the rivers that drain into key water bodies. Most of the lakes fed by the rivers originating from the Water Towers are transboundary resources, making them important catchments not only for the country but also the region. The three Water Towers have unique fauna that contribute to tourism earnings and prime foreign-exchange earnings in the country. However, the Water Towers face immense challenges, including encroachment, conversion to agricultural land and human settlement, overgrazing, forest fires, and illegal harvesting and growing conflicts (KFS, 2015).

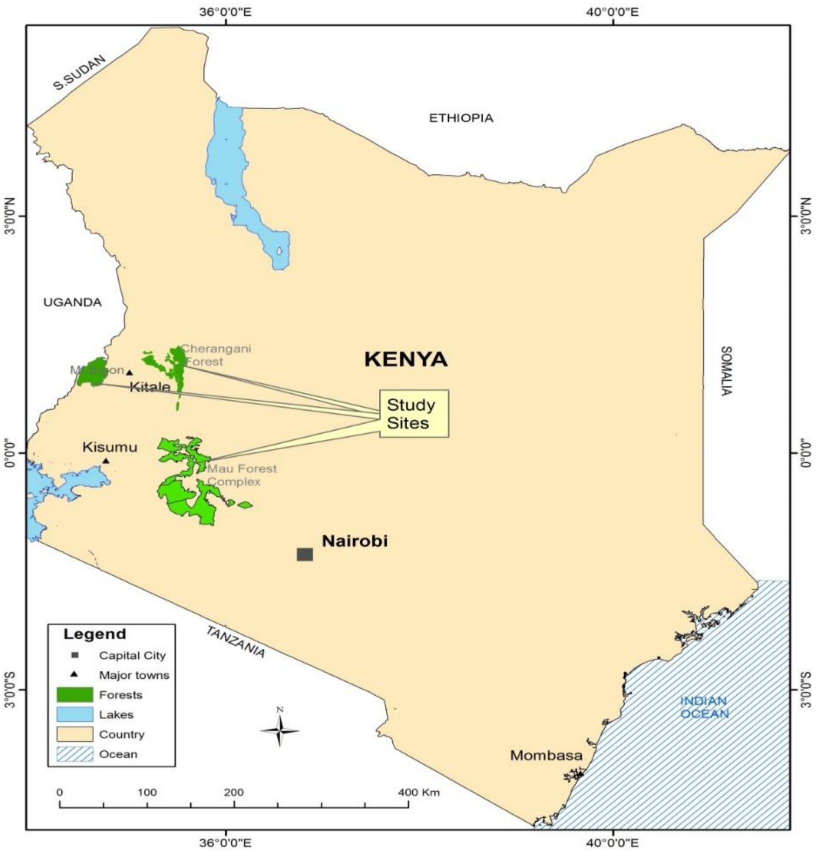

Figure 1. Mau complex, Cherangany Hills, and Mt. Elgon ecosystems in western Kenya

Mau Forest Complex

The Mau Forest Complex forms the largest closed-canopy montane forest ecosystem in East Africa, covering approximately 400,000 hectares. It is situated at 0°30’ South, 35°20’ East within the Rift Valley region. It is the largest Water Tower and is the source of twelve rivers which drain into Lake Baringo, Lake Nakuru, Lake Natron, Lake Turkana, and the transboundary Lake Victoria (Nabutola, 2010; Kipkoech *et al.*, 2011). The rivers Makalia, Nderit, and Njoro support Lake Nakuru ecosystems- one of the largest bird sanctuaries in the world and an important tourism destination (Langat *et al.*, 2016). Additionally, it is the origin of the Mara River, which is a source of water for the wildlife and livestock in the extensive Mara River Basin and ecosystem—a world-famous site for viewing the spectacular wildebeest migration and other tourism attractions, besides a thriving livestock sector. In addition, the Mau complex has an estimated potential hydropower generation of approximately 508 megawatts (GoK, 2009). However, anthropogenic activities have led to drastic and rapid land fragmentation, deforestation, and destruction of wetlands in fertile upstream areas (Olang and Kundu, 2011). For example, in 2001, the Government excised over 67,000 hectares of forest reserve land, mainly in the Mau Complex (UNEP *et al*, 2008). The forest is a habitat for wildlife and unique flora. The species diversity has sacred and cultural values to indigenous communities such as the Ogiek, who have lived in the forest and practice a hunter-gatherer lifestyle. The complex supports wood-based industries and trade, and many local communities depend on forest resources for their livelihoods (Nabutola, 2010; Langat *et al.*, 2016).

Cherangany Forest Ecosystem

The Cherangany forest ecosystem is located within an area defined at 1°16' North 35°26'East. The Cherangany forest ecosystem is comprised of forest reserves totalling 114,416.2 hectares and has unique attractive recreation sites. The Cherangany ecosystem is the source of two major rivers the Nzoia and the Kerio, which drain into Lake Victoria and Turkana respectively. Other rivers include the Mara, Kapolet, Saiwa, Embobut, Siga, and Weiwei. The ecosystem has diversity of floral and animal species and makes its attractive for research and recreation (KFS, 2015). The Saiwa Swamp National Park, which is part of the ecosystem, is habitat to white colobus monkeys, otters, genets, mongooses, bushbucks, and De Brazza's monkeys, as well as the Sitatunga antelope. The bongo antelope (ungulate *Tragelaphus eurycerus*) has been recorded in the ecosystem in the past; although its current status is unknown, the unique fauna attracts tourists in the area. Regionally threatened species found in Cherangany include the bearded vulture (*Gypaetus barbatus*) nesting on the high peaks; the crowned eagle (*Stephanoaetus coronatus*); the red-chested owlet (*Glaucidium tephronotum*); and the purple-throated cuckooshrike (*Campephaga quiscalina*) recently recorded in Kapkanyar Forest. Endemic species in the ecosystem include butterflies like the *Capysjuliae*, which attracts scientists across the world (KFS, 2015). Nevertheless, the ecosystem is facing challenges pressing human activities.

Mt. Elgon Forest Ecosystem

The Mt. Elgon ecosystem lies between 0°52' and 01°25N, and between 34°14' and 34°44E. It is an extensive transboundary resource between Kenya and Uganda—covering 2,223 square kilometres, of which 1,078 square kilometres fall on the Kenyan side. The ecosystem covers an area of about 772,300 hectares—made up of

221,401 hectares of protected areas and 550,899 hectares of farmlands and settlements—of which 180,000 hectares of the forest are in Kenya. The forest is an important regional resource that supports local economies through direct and indirect uses. In addition, the ecosystem provides biological, aesthetic, touristic, cultural, educational, employment, resource, and carbon sink values that are significant and could mitigate poverty and the likely negative effects of climate change.

The forest is rich in bamboo, which communities use for sturdy poles and nutritious bamboo shoots (SGS Qualifor, 2007). The Mt. Elgon ecosystem is habitat to 37 "globally threatened" species (22 mammals, 2 insects, and 13 bird species) and is also home to 9 endemic animals, making the area a priority for species conservation. The alpine chat, long-crested eagle, Cape Robin-chat, and yellow-whiskered greenbul are among the 240 documented bird species. A total of 67 reptiles and amphibians and 179 species of butterflies have also been documented in the Mt. Elgon region (Larsen, 1991; Davenport, 1996; Makenzi, 2016).

Conceptual framework linking ecosystem services and human well-being

There have been discussions in the ecosystem-services literature regarding the need for a unified conceptual framework linking nature's benefits to human welfare. One of the outstanding contributions in this area is the Millennium Ecosystem Assessment (MEA, 2005). The MEA and the total economic value framework (TEV) articulate links between ecosystem services and human well-being and livelihoods. The framework recognizes four main ecosystem values, namely: provisioning services (direct-use values), regulating services, supporting services, and cultural and information services.

Provisioning services include goods or products that are directly used or consumed—food, water, fiber, fodder, medicines, and so on. Regulating services are benefits people obtain as a result of nature's regulation of natural processes—water purification, water storage, climate regulation, erosion control, and so forth. Supporting services are the foundational building blocks of natural systems, including soil formation, nutrient cycling, and pollination. Cultural services refer to non-material or intangible benefits related to spirituality, heritage, aesthetics, recreation, and educational experiences.

Ecosystem services are often described as "direct" or "indirect" depending on the process by which people benefit from ecological processes and functions. Direct-use values include goods consumed, including most provisioning services such as timber, food, and water. Indirect-use values encompass many regulating and supporting services that result in the production of a tangible benefit, such as flood protection or pollination of crops. Non-use values reflect the importance attributed to an aspect of the environment irrespective of its direct use, such as the value placed on knowing that certain landscape features or species exist, even if we do not directly interact with them. The sum total of use and non-use values associated with a landscape is defined as Total Economic Value (Figure 2).

The MEA typology and assessments of total economic value applied here will support alignment between estimations of natural capital in Kenya and other accounting efforts occurring globally. These include the Economics of Ecosystems and Biodiversity (TEEB), a global initiative created by environment ministers from the G8+5 countries that focuses on prioritizing the values of biodiversity and ecosystem services into decision-making at all levels. Wealth Accounting and the Valuation of Ecosystem Services (WAVES) is a global partnership led by the World Bank aiming to promote sustainable development by ensuring that natural resources are mainstreamed in planning and national economic accounts. The application of related concepts and methods in this assessment facilitates consistency with natural capital initiatives occurring regionally and internationally.

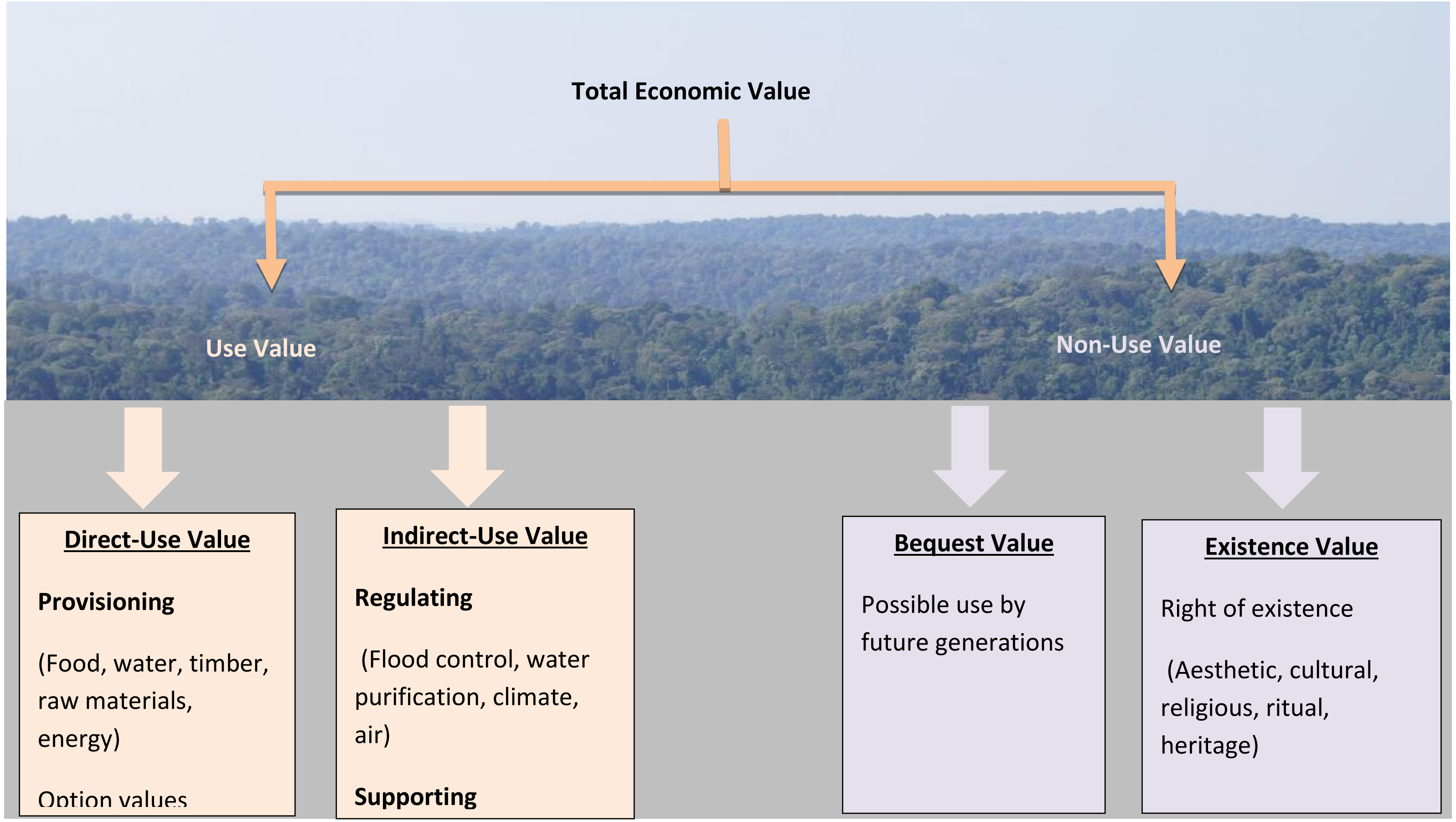

Figure 2. Relation between ecosystem functions, ecosystem services and economic values (adapted from MEA, 2005, and Nahuelhual *et al.*, 2007)

Primary data collection

Household surveys in the case-study areas

Study area

Primary data was collected from forest-adjacent households of Southwest Mau, Cherangany, and Mt. Elgon.

Research design, sample sand selection

In this study, a cross-sectional survey design was used to collect forest use data from sampled households in each ecosystem using structured and semi-structured interview approach and Participatory Rural Appraisal (PRA) techniques from December 2016 to March 2017. The study population consisted of all households within the five –kilometer distance from the forest boundary was the study population. The forest adjacent households in all the three Water towers were delineation and mapped using GIS techniques. The total forest adjacent population was estimated using the Kenya National Bureau of Statistics 2009, census data and extrapolated to year 2016. Selection of target villages was made in consultation with the local administration. Multistage simple random sampling procedure was used to select first the forest adjacent sub locations and secondly the adjacent villages were randomly selected. Respondent households were then chosen randomly from a total household list using simple random and systematic procedures. Villages from 17 sub-locations and 1,206 households were sampled (Table 1).

Table 1. Sampled households study sites of Mau , Cherangany and Mt Elgon ecosystems

Forest Ecosystem	Forest Block	Sampled Sub-Location	Total Households	Sampled Households
Mau complex	Southwest Mau	Embomos	918	60
		Siomo	462	52
		Besiobei	696	56
		Chematich	1,150	65
		Chemare	2,789	224
	Subtotal		**6,015**	**457**
Cherangany	Kipkunur	Kipsaiya	532	35
		Kapsumai	1,108	53
		Kapsowar	1,508	83
		Kamasia	370	28
	Chemurkoi	Kibigos	904	63
	Toropket	Kokwongoi	274	18
	Kaisungur	Kimnai	639	44
	Subtotal		**5,335**	**324**
Mt. Elgon	Saboti/Kaboywo	Kaptaleli	713	49
		Kongit	1,071	65
		Kaboywo	823	59
	Trans Nzoia	Kiboroa	1,947	120
		Teldet	2,136	132
	Subtotal		**6,690**	**425**
	Total		**18,040**	**1,206**

Sources: Kenya Population Census, 2009, and households' own estimation, 2016

Valuation techniques, data needs and sources

The valuation techniques, data need and sources were identified before the study and this informed the type of data to be collected and their sources. These were identified through rigorous review of Ecosystem Services literature, expert consultation and discussions with experts (see annex 1).

Household forest use surveys

Structured closed questions and semi-structured questions were used to obtain quantitative data on forest use (frequency of forest use, quantities collected per visit, time spent, number of household members involved, costs of forest activities, costs and benefits of conservation). Socio-economic and demographic data were also obtained from household surveys. The Contingent Valuation Method (CVM) was used to determine Willingness to Pay (WTP) for the maintenance of the forest for medicinal, cultural, and bequest values. CVM surveys were conducted according to the guidelines suggested in Mitchell and Carson (1989), Whittington (2002); Hanley *et al*. (2007), Ojeda *et al*. (2007), Ezebilo and Mattsson (2010), and Riera and Signorello (2013). This involved i) setting up a hypothetical market for medicinal herbs, cultural and bequest values, (ii) describing hypothetical scenarios on conservation measures and a description of a payment vehicle (levy); (iii) obtaining bids by asking respondents to state the maximum amount they would be willing to pay to achieve the conservation objectives; (iv) estimating mean WTP; and aggregating data to total population of the forest adjacent households.

Wood industry and forest trade survey

This was aimed at obtaining economic data on wood processing and trade within the major towns and townships adjacent to Mau, Cherangany, and Mt. Elgon ecosystems. To capture exhaustively the various players in the forest industry, a list of all the major timber-based enterprises in the three ecosystems was obtained from Kenya Forest Service (KFS), focusing on primary licensed wood processors (sawmills, plywood mills), integrated sawmills (large, medium, and small) and wood treatment plants. A twenty percent sampling intensity was applied for sawmills in Mau and Cherangany and 50 % for Mt. Elgon. Sawmills in Mt. Elgon were small-scale and therefore sampling intensity was increased to compensate for the absence of the other large mill category. The sampling for the small-scale traders was challenging because most of the enterprises were informal and getting the accurate number was difficult and so a snowball sampling strategy with 5 to 10 % sampling intensity was adopted due time and logistical constraints. One hundred and forty-eight (148) forest enterprises were sampled: Mau (69), Cherangany (38) and Mt. Elgon (41) (Table 2). The data obtained from wood processing players were: the volume of saw logs (m^3); the proportion of raw materials sourced from the respective forest ecosystem (Mau, Cherangany, and Mt. Elgon); the number of people employed in logging, processing, and sales; and the prices of various wood products. The survey also covered secondary players such as timber, charcoal, firewood, and construction-pole enterprises. The following data were collected from traders included: the nature and volume of products (saw logs [m^3], poles [units/year], charcoal [kilograms/year], firewood [kilograms/year] and the number of people employed in the processing and business.

Table 2. Sample size for different forest enterprises in Mau , Cherangany and Mt Elgon ecosystems

Category of Forest Enterprise		Number of Enterprises Within the Ecosystem			Number Sampled (n)		
		Mau	Cherangany	Mt. Elgon	Mau	Cherangany	Mt. Elgon
Sawmills	Large	17	2	-	7	1	-
	Medium	62	6	-	13	5	-
	Small	73	43	12	13	4	6
Timber treatment plants		4	7	1	4	3	1
Small-scale enterprise	Charcoal	200	150	150	7	7	7
	Firewood	120	100	100	8	4	8
	Poles	100	100	100	9	6	9
	Timber	300	200	200	8	8	10
Subtotal					69	38	41
Total	**148**						

Sources: KFS records and own calculation, 2017

Participatory valuation techniques and expert discussion forums

Focus Group Discussions were conducted to establish the ecosystem services (ES) enjoyed by the forest-adjacent households and other stakeholders. The data collected was intended to complement household surveys, forest-products market surveys, and secondary datasets in order to estimate the total economic values (TEV) of the three ecosystems. The participants in the Focus Group Discussions included local administrators, Kenya Forest Service (KFS) officers, Community Forest Association (CFA) officials, Water Resource Users Association (WRUA) officials, religious leaders, village elders and key community leaders of all ages, and county government officers. The discussions were guided through a prepared check list and focused on the history of the ecosystem, products and services, and seasonal fluctuations and their relative importance to different stakeholders. To understand the importance of the products and services enjoyed by local communities from the forest ecosystems, the weighted ranking method (Pebble Distribution Method) was adapted (Lynam *et al*., 2006).

Secondary data collection

Secondary data on the importance of Mau, Cherangany, and Mt. Elgon forest ecosystems to the local communities and their livelihoods were collected from reports, bulletins, and documents from county government departments of agriculture, water, and energy; research organizations; journal articles; and online resources. Agricultural statistics on crop productivity, production costs, and market prices of crops and livestock were obtained from Department of Agriculture sub-county offices. The livestock data from forest-adjacent areas were obtained from the Kenya National Bureau of Statistics (KNBS) 2009 livestock census and extrapolated to 2016 using the

1990 to 2000 annualized livestock population growth rate in Kenya of 3.5 percent (FAO, 2005). The livestock population was converted to tropical livestock units (TLU) using livestock conversion factors (Jahnke, 1982). Livestock dry fodder and water requirements per tropical livestock unit per year were obtained from the literature (Ganesan, 1993). Hydrological data; water yields from rivers; uses related to subsistence, commercial, industrial, irrigation and volumes extracted per year; and borehole characteristics (water yields, costs of drilling and commissioning, and allowable abstractions per year) were obtained from the Water Resources Management Authority (WRMA), Water Service Boards (WSB), and Water Service Providers (WSP). Sediment yield data from various rivers originating from the three Water Towers were obtained from published reports and scientific papers. Forest production data on the size of land under productive forests, harvestable volumes, value of sales per year, revenues from non-extractive uses, licenses and permits, land under Plantation Establishment for Livelihood Improvement Scheme (PELIS), crops grown and estimated production per unit area, and costs of operations were obtained from Kenya Forest Service (at the conservancy and county level). Tourism data were obtained from Kenya Wild Life Service.

Data analysis

Computation model of total economic value of forests

Comprehensive value to forests include direct-use value (DUV), Indirect use Value (IUV), existence value (EV) and option value (OV). The TEV of forests can be calculated from a combination of all these values by the use of the model given in the form:

$$T_{ev} = D_{uv} + I_{uv} + E_v + O_v \quad \text{......1}$$

T_{ev} = f (D_{uv}, I_{uv}, E_v, O_v) where, TEV -Total Economic Value; D_{uv} - Direct-Use Value; I_{uv}- Indirect-Use Value; E_v- Existence Value and O_v- Option Value

There are quite a number of methods that has been developed by economist to capture the total economic value of forests. Combinations of these methods have been used for this study. There is no one approach that can capture all the forest values. The Table 3 below shows applicable formulae for estimating ES values.

Table 3. Computation Models for ES Values

Ecosystem Service(s)	Equation model	Explanations	References
Direct use Values			
Firewood, fencing/constructions poles, forest honey, timber, thatching grass, game meat	$T_n = (Q_i * P_i) - C_i)) * (\partial * N_i)$	Where, Q_i is the quantity of good extracted; P_i is the forest gate price of the product (in the absence of externalities), C_i is the transaction cost (costs of collection, transport, and sale), ∂ is the proportion (percentage) of local households deriving benefit from the local forest, and N_i is the total number of forest adjacent (2016)	Godoy *et al*., 1993; Campbell and Luckert, 2002; Langat and Cheboiwo, 2010; Langat *et al*., 2016.
Herbal Medicine	$V_m = \sum_i^n (W_i * N_i)$	Vm- is the value of medicinal use; W_i- WTP, N_i- number of households in each ecosystems	Ezebilo and Mattsson (2010)
Fodder (Grazing/browse)	$E_f = \left[\frac{TLU * \beta * f_m * \alpha}{\partial}\right] * P_h$	Where E_f is the total value of forest fodder, TLU indicates the tropical livestock units sourcing fodder from forest; β is the proportion of forest fodder in livestock diet; f_m is the minimum fodder requirement for one tropical livestock unit; and α is the rate of technical substitution (RTS) of forest fodder to hay; ∂ is the weight of air dry hay (25kg), P_h *is* market price of hay	Ganesan, 1993, Jahnke, 1982, Hufschmidt *et al*., 1983; Emerton, 2001; Gunatilake, 1998; Mogaka, 2001; Emerton, 2014; Langat *et al*., 2016
Water provision (human and livestock)	$E_{dw} = \left[\frac{(T_i * \delta_i) + (Q_i * N_i)}{\lambda}\right] * C_b$	E_{dw}- Value of domestic water, T_i- total TLUs; δ_i- Average consumption of water /TLU/yr, Q_i-Household consumption of water /yr, λ- average borehole yield/year, C_b- is the cost of drilling borehole and commissioning	Sjaastad *et al*.,2003, Bush, 2009, Padden undated

Ecosystem Service(s)	Equation model	Explanations	References
Industrial and commercial water	$V_{ic} = \sum_{i=1}^{n} (Q_i * P_i)$	Where V_{ic} is the value of industrial and commercial water abstraction, Q_i is the quantity of water and P_i is the current average unit price of water.	Langat *et al.*, 2018
Hydropower generation	$V_e = P_e * Q_e$	V_e –is the value of hydroelectric power generated; P_e is the on –grid power tariff; Q_e- is the annual average quantity of hydroelectric power generated	Wang *et al.*, 2010
Value added from wood industry and trade	$V_a = \sum_{0}^{n} (G_v - (M_c + S_c + FV_c) * N_i$	Where V_a represents the total value added, G_v indicates gross value, M_c signifies material costs, S_c represents the change in stock costs of materials and supplies, and FV_c stands for fixed and variable costs, N_i – number enterprise	Langat *et al.*, 2018
Indirect use values			
Soil nutrient conservation	$V_f = d * S * \sum_{i=1}^{n} P_{1i} * P_{2i} * P_{3i}$	Where V_f is the economic value of soil-nutrient conservation of forest land; d-is the reduced erosion of forestland compared to agricultural or non-forest land (t/ha); S_i is the area of forest-vegetation types in hectares; P1i is the content of N,P,K in forest soils (%), P2i is the proportion of pure N,P, K converted to chemical fertilize, P3i is the local price of chemical fertilizer (KES/ton)	Xue and Tisdalle, 2001, Xia and Guangcan, 2002, Xi, 2009, Okelo, 2008, Okungu and Opango, 2005
Soil protection (erosion control)	$V_k = K * G \sum_{n=1}^{n} S_i * (d_i - d_0)$	Where V_k is the economic value of soil-erosion regulation; K is the cost of 1 ton of sediment removal; S_i is the area of forest-vegetation types in hectares; G is the ratio of sediment entering rivers or reservoirs to total soil lost; d_i is the erosivity of all forest vegetation types	

Ecosystem Service(s)	Equation model	Explanations	References
		(tons/ha); and d_o is the erosivity of non-forest land, or agricultural land (tons/ha).	
Water-flow regulation	$V_f = S * (J_0 * K) * (R_0 - R_q) * C_{yt}$	Where V_f represents the value of water-flow regulation; Q represents the increase in water preserved in forest ecosystems, compared to agricultural land (bare land; m^3); S represents the area under forest in hectares (indigenous vegetation only); J represents the annual precipitation runoff of the study area; J_o represents the annual precipitation of the study area; K represents the ratio of precipitation-runoff yield to the total precipitation of the study area; R represents the beneficial coefficient of reduced runoff of forest to non-forest area; R_o represents the precipitation-runoff rate under precipitation-runoff conditions on agricultural land; R_g represents the precipitation-runoff rate under precipitation-runoff conditions in forests; and C_{yt} represents the investment cost of reservoir construction per m^3.	
Water-quality regulation	$V_p = Q_i * P_i$	Where V_p is the value of water purification by the forest; Q_i is the amount of water sourced by adjacent households from the water tower for domestic consumption; and P_i is the unit cost of water treatment.	WHO, 2008
Carbon sequestration	$V_s = Q_i * P_c * S_i$	Where V_s is the release or absorption service value; Q_i is carbon sequestration (CO_2); P_c is the international carbon sequestration price; S_i is the area of each forest type (in	Kinyanjui *et al*. (2014) Otuoma (2015),IPCC, 2003; Olschewski *et al*., 2010, Xi (2009) Patton *et*

Ecosystem Service(s)	Equation model	Explanations	References
		hectares).	*al*. (2011), World Bank (2014), CDP (2013), Environmental and Energy Study Institute (2012)
Oxygen generation	$V_o = Q_i * P_o * S_i$	Where V_o is the release or absorption service value; Q_i is O_2 generated P_o is the local price of industrial Oxygen in Kenya; S_i is the area of each forest type (in hectares).	Xi (2009), Langat *et al*., 2018
Microclimate influence agriculture	$V_t = \sum_{1}^{n} \{\varphi_i * \gamma_i * (P_i) - (C_i) * A_i\}$	V_t- Value attributed microclimate influence φ-factor contribution ratio; γ-crop yield; P_i- farm gate price of crop, C_i- unit cost of production; A_i-area under crop	Kipkoech *et al*., 2011
Pollination	$V_p = \sum_{1}^{n} \{\varphi_i * \gamma_i * (P_i) - (C_i) * A_i\}$	V_p- Value attributed microclimate influence φ-pollination dependence ratio; γ-crop yield; P_i- farm gate price of crop, C_i- unit cost of production; A_i-area under crop	Kasina *et al*., 2007,FAO
Non-use values			
Cultural and spiritual	$V_c = \sum_{i}^{n} (W_c * N_c)$	V_c- is the value of cultural use; W_i- WTP, N_c- number of households in each ecosystems using forest	Ezebilo and Mattsson (2010), Langat et al., 2018
Bequest	$V_b = \sum_{i}^{n} (W_b * N_b)$	V_b- is the value of medicinal use; W_b- WTP, N_b- number of households in each ecosystems	Ezebilo and Mattsson (2010), Langat et al., 2018
Option value (pharmaceutical value)	$V_{EM} = BV_{Cx} * \left[\frac{PPP_{GNPKenya}}{PPP_{GNPCountry\ x}}\right]^E$	Where V_{EM} is the biodiversity value of Mau, Cherangany, and Mt. Elgon forest ecosystems; B is the biodiversity correction factor for the study and policy site; V_{cx} is the Value transfer from study site (country) corrected to	Navrud and Brouwer, 2007; UNEP, 2011, World Bank, 2014, Ruitenbeek,

Ecosystem Service(s)	**Equation model**	**Explanations**	**References**
		2016; PPP GNP is the purchasing power parity gross national product per capita (World Bank, 2014); and E is the elasticity of values with respect to real income (assumed E=1.00).	1989

Results and Discussions

The study identified a diversity of ecosystem services from the three Water Towers, including: Provisioning services, such as fuel wood; construction materials (timber, poles, thatch); fodder; food (fruits, game meat); planted food crops (maize, potatoes, peas, among others); utility forest soils (murram for constructing roads and buildings, decorative soils); water (domestic, industrial, irrigation use); and hydropower generation. These ES contribute directly to the livelihoods of the local community members through direct consumption and as inputs to various livelihood activities. In addition, the ES contribute to economic sectors by supplying raw materials and inputs in production processes. The three Water Towers also support key agricultural sectors by providing irrigation water and soil nutrients. In addition, the Water Towers provide regulating services such as climate regulation, oxygen generation, water-flow regulation, and water-quality regulation and supporting services, such as soil conservation, nutrient conservation, and pollination. These ES are important to all stakeholders at different levels—local, regional, national, and global. The flow of these ES is important for various economic activities like agriculture, flood control, and provision of quality water for human well-being at different scales. These ES have indirect influences in productive sectors of the economy. For example, about 75 percent of the local population depends upon agriculture for their livelihoods (KARI, 2012). Furthermore, the Water Towers provide cultural and education services, such as spiritual, aesthetic, and bequest values. Though these ES are difficult to measure, they remain a very important component to satisfying human values.

The most important direct-use value for the local communities in Mau, Cherangany, and Mt. Elgon is animal fodder, with present values of KES 3.0, 2.2, and 1.0 billion respectively (Table 4). The animal browse and fodder constitutes about one-third of the total monetary value of products which is 30.9 percent total direct use value obtained by the communities from the three Water Towers. The weighted contribution of fodder to total household consumptive value is considerably high in all the three water towers, contributing 25 %, 40 % and 32 % respectively for Mau, Cherangany and Mt. Elgon (Table 5 and Figure 3). This data underscores the important role the forests play in supporting the livestock industry. The aggregate monetary value of fodder resources (browse and grazing) was KES 7 billion. This study confirms that forest grazing contributes significantly to the local economies especially during dry seasons. Similar results were reported by Emerton (2001) and Langat *et al* (2016). Poles for construction and for cash income are very important to households, contributing about 20 percent to the aggregate monetary value. Water for human and livestock use accounted to 17.8 percent of direct use value by the local communities.

The aggregate monetary value of these products for all the three Water Towers was estimated at KES 23 billion per year, with KES 12.5 billion, 7 billion, and 3.4 billion per year respectively for Mau, Cherangany, and Mt. Elgon (Table 4). The water Towers support various wood processing industries through provision of raw materials, creation of employment, and revenue sources to government agencies via permits and licenses. The estimated annual values in the three Water Towers were KES 10.7 billion, KES 3.4 billion, and KES 1.5 billion as valued added to the forest industry, wages, and revenue to government respectively. Furthermore, the three Water Towers support small-scale traders, thus supporting livelihoods and local economies.

Table 4. Aggregate annual households' consumptive values (2017) per product in Mau, Cherangany and Mt. Elgon ecosystems

Forest Product	**Aggregate Annual Value (KES)**				
	Forest Ecosystem			**Aggregate Annual Value (all)**	**Proportion (%)**
	Mau	**Cherangany**	**Mt. Elgon**		
Animal fodder	3,183,031,000	2,808,086,125	1,095,020,804	7,086,137,929	30.9
Poles	2,380,586,000	1,359,887,743	847,733,944	2,257,118,687	20.0
Water	2,958,797,000	758,529,000	366,165,973	1,129,359,973	17.8
Firewood	2,094,128,000	389,615,459	482,308,193	921,173,652	12.9
Fruits	1,457,562,000	190,760,794	115,082,148	305,865,942	7.7
Honey	47,839,000	841,526,994	16,996,108	2,316,085,102	4.0
Charcoal	22,404,000	197,033,558	181,538,745	400,976,303	1.7
Game Meat	196,779,000	95,383,510	46,848,326	190,070,836	1.5
Medicine	15,287,000	225,206,693	88,421,877	510,407,570	1.4
Agricultural tools	60,811,000	64,357,033	76,102,335	201,270,368	0.9
Mushrooms	49,497,000	2,116,823	60,199,640	77,603,463	0.5
Fibers	49,250,000	5,642,414	11,969,635	2,976,409,049	0.3
Thatch grass	4,978,000	26,710,613	13,733,809	2,421,030,422	0.2
Timber	4,665,000	10,275,056	36,905,034	52,158,090	0.2
Murram/soils	23,000	1,202,152	592,815	2,095,922,967	0.0
Total	**12,525,637,000**	**6,976,333,967**	**3,439,619,386**	**22,941,590,353**	**100.0**

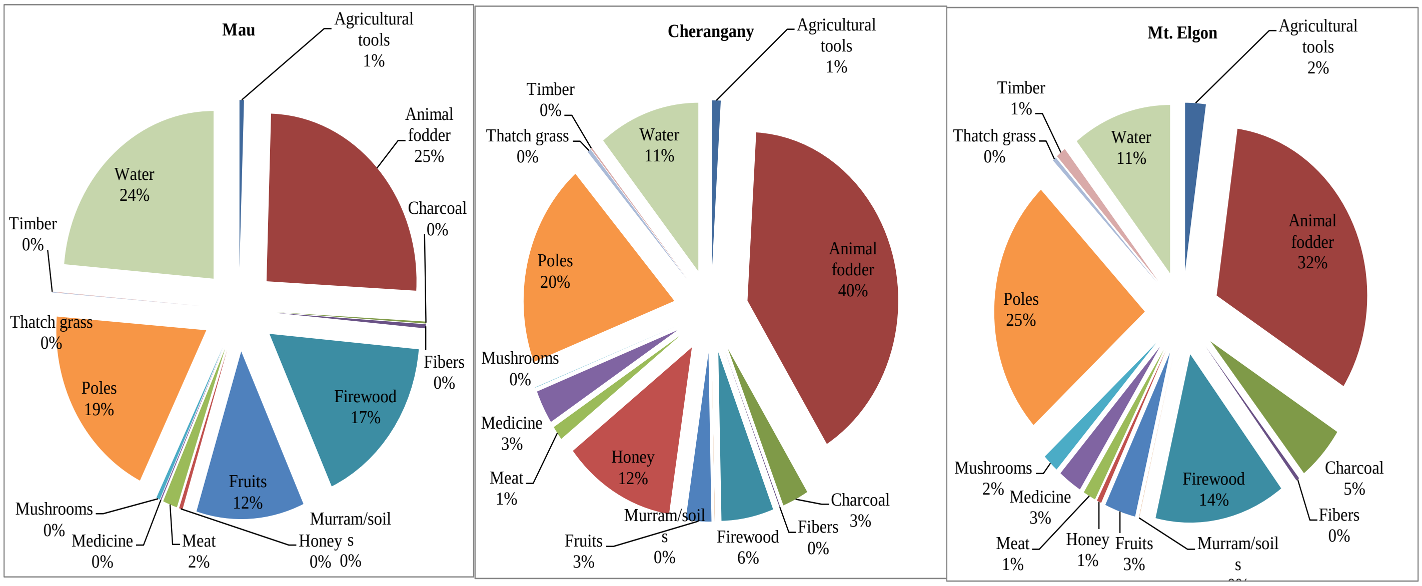

Figure 3. Weighted % contribution of product values to total households' consumptive values in Mau, Cherangany and Mt. Elgon

The study revealed that the total economic value (TEV) of the three ecosystems is about KES 350 billion (USD 3.5 billion) per year, as outlined in Table 5. The Mau forest ecosystem had the highest total monetary value, due to its large size and abundant resources available for various stakeholders. Moreover, the Mau complex neighbors high-population areas highly dependent on the resources. In terms of relative contributions to total value, regulating services comprise the greatest component of TEV at 88.8 percent, underscoring the importance of indirect-use values in forest ecosystems (Table 5 and Figure 4). Provisioning services followed at 9.4 percent. These results are comparable to a similar study by Kipkoech *et al.* (2011) conducted in three areas of Mau—East Mau, Maasai Mau, and Trans Mara where indirect-use (regulating and supporting) and provisioning services contributed 86 percent and 12.4 percent to TEV respectively. The two studies have brought out the importance of indirect-use values, which were hitherto not valued. It should also be noted that this study did not exhaust all ES; hence, it inevitably underestimated the TEV of the Water Towers.

Table 5. Total Economic Value for Mau, Cherangany, and Mt. Elgon ecosystems

ES Type	ES	Annual value(KES)	Annual value(USD)	% contribution TEV
Provisioning	Timber & non-timber	5,930,051,000	259,300,510	7.4
	Food production	634,770,000	6,347,700	0.2
	Water	3,427,027,000	34,270,270	1.0
	Hydropower	11,983,679,000	119,836,790	3.4
	Option value	309,665,000	3,096,650	0.1
		42,285,192,000	**422,851,920**	**12.1**
Regulating	Water flow	2,960,143,000	29,601,430	0.8
	Water quality	1,155,366,000	11,553,660	0.3
	Carbon sequestration	176,657,067,000	1,766,570,670	50.4
	Oxygen generation	118,461,049,000	1,184,610,490	33.8
	Microclimatic regulation	2,099,161,000	20,991,610	0.6
		301,332,786,000	**3,013,327,860**	**85.9**
Supporting	Soil conservation	1,060,000,000	10,600,000	0.3
	nutrient conservation	4,499,000,000	44,990,000	1.3
	Pollination	930,564,000	9,305,640	0.3
		6,489,564,000	**64,895,640**	**1.85**
Cultural	Cultural and spiritual	235,358,000	2,353,580	0.1
	Bequest	297,905,000	2,979,050	0.1
		533,263,000	**5,332,630**	**0.15**
	TOTAL	**350,640,805,000**	**3,506,408,050**	**100**

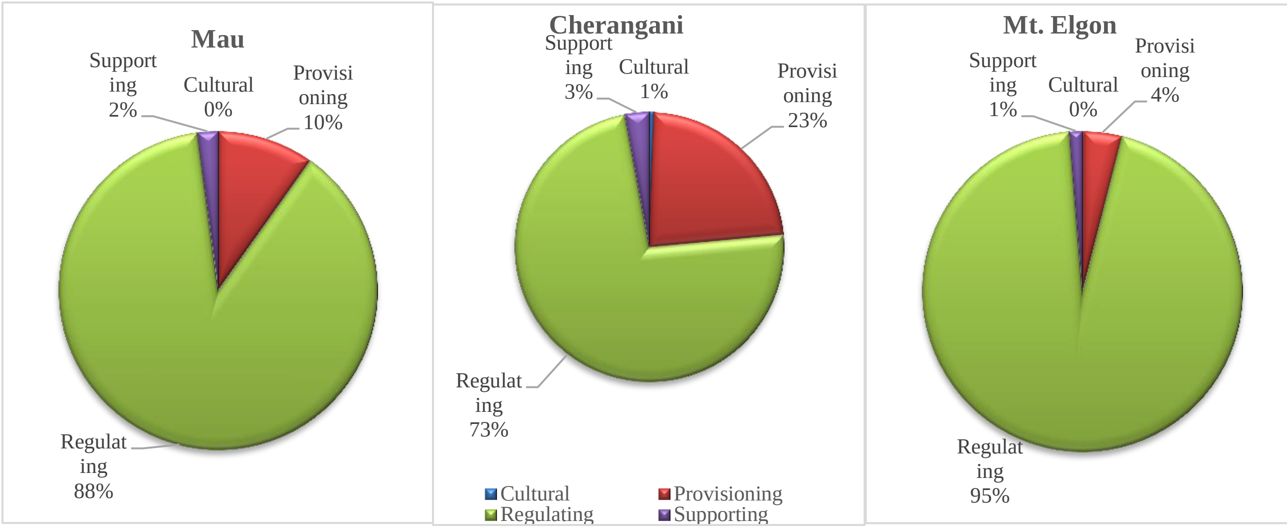

Figure 4. Weighted contribution (%) ES typoes to TEV in Mau, Cherangany Hills, and Mt. Elgon ecosystems

Distribution of benefits of ecosystem services in Water Towers

Determining the distribution of benefits among different stakeholders in society allows for quantitative analysis of externalities. The benefits valued in this study and where they accrue in the value chain (from local to global) are shown in Table 5I. Apart from supporting local communities and the national economy, the Water Towers are important to the global community because of their regulating and supporting services- public and global values.

Table 5. Distribution of ES benefits among stakeholders

Beneficiary	ES	Annual value(KES)	Annual value(USD)	% contribution TEV
Global	Biodiversity	309,665,000	3,096,650	0.1
	Carbon sequestration	176,657,067,000	1,766,570,670	50.4
	Oxygen generation	118,461,049,000	1,184,610,490	33.8
		295,427,781,000	**2,954,277,810**	**84.3**
Local	Cultural and spiritual	235,358,000	2,353,580	0.1
	Bequest	297,905,000	2,979,050	0.1
	Timber & non-timber	25,930,051,000	259,300,510	7.4
	Food production	634,770,000	6,347,700	0.2
	Water	3,427,027,000	34,270,270	1.0
	Soil conservation	1,060,000,000	10,600,000	0.3
	Nutrient Conservation	4,499,000,000	44,990,000	1.3
	Pollination	930,564,000	9,305,640	0.3
		37,014,675,000	**370,146,750**	**10.6**
National	Hydropower	11,983,679,000	119,836,790	3.4

Water Flow	2,960,143,000	29,601,430	0.8
Water Quality Regulation	1,155,366,000	11,553,660	0.3
Microclimatic Regulation	2,099,161,000	20,991,610	0.6
	18,198,349,000	**181,983,490**	**5.19**
Total	**350,640,805,000**	**3,506,408,050**	**100**

Beyond ecosystem services valuation: policy implications and recommendations

The economic benefits supplied by the Water Towers ecosystems play a significant role in the livelihoods of local, regional, and national communities, while also contributing significantly to national GDP. Decision making on the sustainable management of these ecosystems can be anchored in these derived economic benefits. Policymakers, including county and national government officials, should therefore fully consider the spatial and temporal ecosystem service provisions in their development plans, and they should consider intelligent resource allocation that reflects the ecological and socioeconomic importance of the Water Towers ecosystems.

Primary data collected in this study highlight the importance of understanding community dependence on forests when making decisions about natural-resource management. The ways in which households rely on forests, as well as threats to those benefits, vary across space and time. Development efforts are well-served by accounting for the ecosystem service tradeoffs involved at local, regional, and national scales due to the loss of natural forest cover. This study can inform decisions on community dependence and ecosystem resilience as well as promote participatory forest management, as recommended by Kenya's Vision 2030. Ecosystem service values identified will inform public and private investments in Water Towers conservation. The Kenya Water Towers Agency Strategic Plan 2016–2020 (KWTA, 2016) highlights the importance of ecosystem services valuation in supporting county-level integrated development plans and ecosystem management plans. In addition, the Kenya National Forest Programme 2016–2030 (GoK, 2016) also highlights challenges in forest financing, including; inadequate synthesized data on the TEV of forests and their contribution to the national GDP.

Kenya's Constitution and Vision 2030 target a 10 percent forest-cover commitment for the country, but without real evidence on the contribution of forests to the national economy, action to meet this goal cannot be effected. This study contributes a more accurate reflection of the contribution of the Kenya Water Towers to the national GDP, and can therefore influence attitudes at all levels and increase commitments to the sustainable management of forest ecosystems that comprise the most significant water tower landscapes in the country.

To improve further upon these assessments, there is need to:

- Improve data collection, storage, and sharing among all stakeholders in the natural-resource sector. For example, the authors faced challenges in accessing existing data on water resources and tourism, while data on livelihoods and the forest industry are poorly developed.
- Build capacity on data collection, processing, use, and reporting for all of the stakeholders, including local, county, and national community-based organizations, such as Community Forest Associations, and Water Resource Users Associations.
- Promote collaborative engagement between national-sector agencies and the county governments in information-gathering analysis and use. The disconnect between national government plans and the expectations of the local communities and county governments—for instance, the construction of dams in Itare and Bosto in the Mau ecosystem—highlights this need.
- Incorporate ecosystem-service mapping to identify both strategic areas providing key services and hotspots for intervention measures. A recent unpublished study by CIFOR in Southwest Mau shows an increase in forest degradation, associated with the production of charcoal and domestic energy demand. This degradation ultimately affects ecosystem-service provisioning. Continuous mapping of the changes in ecosystem integrity and function is needed to define the capacity of the ecosystem to provide various services.
- Develop a continuous monitoring system that considers the effects of climate change on forest conditions, as well as the benefits they provide.
- Accelerate and promote activities aimed at rehabilitating degraded sections of the Water Towers ecosystems to enhance resilience and adaptation while ensuring the flow of ecosystem services from these landscapes. The government of Kenya has pledged to restore 5.1 million forest hectares by 2030. This would produce an estimated USD 1,601 million in economic benefits while also sequestering 0.48 gigatons of carbon dioxide.[2] Activities that contribute to this goal, such as the Initiative for Sustainable Landscapes (ISLA Kenya) supported through the Sustainable Trade Initiative aims to restore and conserve 60,000 hectares of the forest by 2030.
- Rehabilitate and protect forests to ensure sustainable ecosystem-service flows. Deforestation is a particular concern in the Mau complex. A recent study by Bewernick (2016) shows a high level of degradation due to charcoal production. A recent study by CIFOR in Southwest Mau indicates a likely loss of water supply and water-quality regulation, due to degradation, as compared to natural forest cover
- Develop and promote public and private partnerships in ecosystem conservation to ensure the sustainable flow of services from the Water Tower ecosystems. The public sector has a relatively limited appreciation of the benefits of such partnerships, while the

[2] For more information, visit www.bonnchallenge.org/content/kenya.

private sector still does not fully realize how much their various economic sectors depend on ecosystem services, such as flash-flood protection, water inputs, and energy supply (Rhino Ark, 2015) Understanding relationships between land-management practices and ecosystem-service benefits can provide a platform for watershed investments at various scales, from community-based programs to landscape-level restoration.

It is important to consider how this ESV assessment contributes to Kenya's capacity to assess its natural capital, a key recommendation in the Kenya Biodiversity Atlas. As these Water Towers fall under the jurisdictions of various counties, this assessment can inform county-level natural-capital accounting to develop strategies, incentives, and programs that increase the flow of ecosystem services, community empowerment, and sustainable resource use. In partnership with other stakeholders, including community-based organizations, county governments could use this assessment to identify and improve the recording and mapping of ecosystem-service flows. The valuation reported here can also contribute to achieving Objectives 3.1, 3.2, 3.3, and 3.5 under the Sustainable Natural Resources Management Thematic Area of the government of Kenya's Green Economy Strategy and Implementation Plan, 2016–2030 (GESIP), recently launched and the Kenya Water Master plan (MENR, 2012). The GESIP specifically outlines the need for a natural-resource accounting system, as well as the application of payment for ecosystem services (PES) programs. Quantifying and valuing ecosystem services flows economically are important preliminary steps in undertaking PES programs to ensure their effectiveness.

Conclusion

Countries across Africa and around the globe are increasingly recognizing the critical importance of natural capital to achieve sustainable development goals. Understanding human dependence on forests and the benefits forests provide serves both economic and conservation objectives. This study assessed the value of Kenya's Water Towers at various scales, from their importance for household well-being to their global contribution to climate regulation. This information can form a strong basis for natural-resource management at county and national levels to support an integrated approach to natural-resource stewardship. This study highlights the relevance of forest lands to diverse constituencies as a means to ensure Kenya's social and economic future.

Acknowledgement

We thank the local communities in Mau, Cherangany, and Mt. Elgon that took part in the surveys, and the research assistants who assisted during the data collection process in the three Water Tower ecosystems. We thank our partner agencies and organizations (KFS, KWS, WRMA, WSB, WSP, KWTA) and County Departments of Agriculture (Nakuru, Bomet, Kericho, Bungoma, Trans-Nzoia, Elgeyo Marakwet, West Pokot, and Uasin Gishu) for providing the data used in this assessment. We acknowledge Mr. Geoffry Maina (Egerton University) for the maps and Mr. Richard Siko (KEFRI) for valuable suggestions during field work and document preparation. The Water Tower Project advisory group played an important role in shaping the scope of this work, and we acknowledge this contribution. We acknowledge the Center for International Forestry Research (CIFOR) in Nairobi and the Kenya Forestry Research Institute (KEFRI) for facilitating and coordinating activities related to this work. We also extend our sincere gratitude to the United States Agency for International Development (USAID) for funding this work and to the US Forest Service (USFS)-International Programs for the technical support to undertake this work. We highly acknowledge the technical guidance provided by professional peers and specialists in various fields, not named here, but whose expert opinions informed this assessment.

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Annex 1. Valuation techniques, data needs , and information sources used in Estimating Ecosystem Services Values of Mau complex, Cherangany and Mt. Elgon forest ecossytems

Ecosystem services	Valuation techniques	Data needs	Data sources
Direct-use values			
Firewood, fencing/constructions poles, forest honey, timber, thatching grass	Market prices	% of households collecting product; amount harvested; amounted extracted by sawmills; market prices; collection and operation costs	Household surveys; focus group discussion with forest-adjacent communities; KFS records, key informants
Game meat, fruit/vegetables, fodder	Market prices of substitute or surrogate/proxies	% of households collecting product; amount harvested; proportion of fodder resources sourced from forests; dry matter requirements per tropical livestock unit (TLU); market prices of substitutes; relevant conversion factors; collection/production costs	Household surveys, FGD with forest-adjacent communities, literature and expert discussions, institutional records (KFS, KWS, county governments etc.), relevant projects reports
Medicinal herbs	Contingent valuation method (CVM)	% of households collecting product; mean WTP of target	CVM surveys, census data (KNBS)

Ecosystem services	Valuation techniques	Data needs	Data sources
		population	
Water provision (human and livestock)	Replacement cost	number of households; household water demand /yr; total livestock units; annual livestock water demand; mean yield of local boreholes ; total water demand (human and livestock)	Household surveys, literature, expert consultations, water service boards, engineering estimates (hydro-geologist/engineers), CCVA study
Industrial/irrigation water use	Market prices	Volume of water extracted by industries, unit price of water charged by WRMA, WSP	WRMA, water service providers (WSP), Irrigation Board, private farms
Hydropower generation	Market prices	Amount of power generated from hydropower stations	Kenya Generation Company (KENGEN), tea companies, literature, expert discussions, CCVA s
Indirect use value			
Soil nutrient conservation	Replacement cost	Mean soil loss per hectare on different land use types; nutrient loss per hectare (loss of major nutrients; nutrient-fertilizer conversion ratios; unit price; operation costs; size of forest area	Literature review, market surveys, expert discussions
Soil protection (erosion control)	Avoided cost	Cost of sediment removal; area vegetation types; ratio of sediments to total soil lost; potential erosivity of all types of forest.	Literature, GIS, water service boards expert discussions (environmental /civil engineers)
Water-flow regulation	Avoided cost	Area under forest (indigenous vegetation only); annual precipitation; ratio of runoff to	Literature, expert consultations, water service boards,

Ecosystem services	Valuation techniques	Data needs	Data sources
		precipitation; beneficial coefficient of reduced runoff of forest to non-forest area; runoff rate under grazing and intact forest; investment cost of reservoir construction per m^3	engineering estimates (hydrogeologist/engineers) , WRA
Water-quality regulation	Cost based	Households' consumption of the water supply; unit cost of water treatment	Household surveys; water service providers; bottling companies or other commercial interests; literature
Carbon sequestration	Benefit transfer, market prices	Area under each forest type; average carbon stock per hectare; carbon sequestration (CO_2); the international carbon-sequestration price	GIS vegetation maps; literature; international market prices of CO_2 permits
Oxygen generation	Surrogate prices	Area under forest; relation between photosynthesis and oxygen generation	Literature, price of industrial oxygen production
B. Non-use values			
Cultural and bequest	Contingent valuation method	Mean WTP and target population	CVM household surveys, population data (KNBS)
Option value	Benefit transfer	Biodiversity correction factor for the sites; biodiversity value; PPP GNP (purchasing power parity GNP per capita; Elasticity of values with respect to real income)	Literature, PPP GNP indices (World Bank)

Evaluating Willingness to Pay for Watershed Protection in Ndaka-ini Dam, Murang'a County, Kenya

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Abstract

Payment for Environmental Services is an incentive based approach in natural resource management aimed at linking the suppliers and consumers of goods and services from a natural resource in a way that both parties contribute to improved delivery. Nairobi City has experienced serious water shortages in the past due to water levels in Ndaka-ini dam subsiding to low levels and resulting in water rationing. The dam supplies 80 % of water to Nairobi city but few of the residents are able to link availability of clean water in their pipes to conservation of water catchments areas. The objective of the study was to find out whether users of water from Ndaka-ini dam could participate in watershed protection scheme through Payment for Water Services. The study identified factors that could influence willingness of water users to pay for the environment services. Primary and secondary data were collected based on baseline survey and qualitative research approaches, interview schedules, questionnaires and, focus group discussions. Results showed that 83% of farmers are willing to participate in scheme aimed at improving conservation. There was significant relationship between farmer's source of water and amount of money they could give but attached condition of clean and regular water. Rewards in kind were more preferred. The government could make use of the findings of the study to develop a payment of environment service model for Ndaka-ini dam.

Introduction

Forests worldwide form vital catchments for rivers that provide water for irrigation, domestic, industrial and power generation thus contributing to growth of the world economies. The Millennium Development Goals (MDGs) had set the agenda for global world growth up to year 2015 (MDG, 2008). Goal number seven aimed at ensuring environmental sustainability with the set targets of integrating principles of sustainable development into country's policies and programme, reversing the loss of the environmental resource, reducing biodiversity loss, and reducing by half the proportion of the population without sustainable access to safe drinking water and basic sanitation by 2015. The report noted that 1.2 billion people in the world lived under conditions of physical water scarcity whose symptoms include, environmental degradation and competition for water. Though access to improved drinking water has expanded, nearly one billion people do without it and its use has grown at more than twice the rate of the population for the past century (MDG, 2008). However, failure to recognize the economic value of water has led to its unsustainable use and degradation of its natural base in many regions of the world (NCCRS, 2010).

The MDGs were replaced with Sustainable Development Goals (SDG) that will guide world development up to 2050. Goal number six aims at ensuring water and sanitation for all. It recognizes that clean and accessible water for all is an essential part of the world we live in and though there is sufficient fresh water on the planet to achieve this, bad economics or poor infrastructure lead to death of millions of people every year most of them children from diseases associated with inadequate water supply, sanitation and hygiene (Universal Sustainable Goals, 2015). The SDG aims at achieving universal and equitable access to safe and affordable drinking water for all; provide access to adequate and equitable sanitation and hygiene, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials. In addition, it aims to half the proportion of untreated wastewater, substantially increase recycling and safe reuse of water globally, substantially increase water-use efficiency across all sectors, ensure sustainable withdrawals and supply of fresh water to address water scarcity, substantially reduce the number of people suffering from water scarcity by 2030 and protect and refurbish water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes by 2020 (UN SDG, 2015).

Millennium development and sustainable development goals in Kenya were operationalized through government blue print contained in Vision 2030, which set a road map for the country's development. It aims at making Kenya a newly industrialized middle-income country with high quality of life for all citizens by 2030 (Vision 2030, 2007). Conservation of water catchments and development of water resources is covered under the Water Act (2016) and the Forests Management and Conservation Act (2016). The Water Act provides a framework for development of water sector in the country with clear institutions for water providers, users and regulators. The Forests Act, provide a framework for involvement of the communities adjacent to a forest resource in conservation and management while addressing the society needs. The main sources of water in Kenya are the commonly referred to five water towers namely: the Aberdares, Mt. Kenya, Mau, Cherangani and Mt. Elgon. In 2012, the water towers were increased from 5 to 18 based on the need to capture other key water towers that supply water in the country (Kenya Water Towers Agency, 2012). According to Kenya Water Master Plan (2013), the main challenges facing conservation and protection of water catchment areas include: weak institutional relations and collaborations, conflicting institutional mandates, lack of clear funding mechanisms for Water Catchment Areas (WCA), inadequate flow of information on WCAs, lack of integrated WCA monitoring and evaluation systems, low levels of awareness and capacity of stakeholders, land degradation (and soil erosion) in WCA, poor management of water resources and waste, water insecurity, livelihood insecurity, over-dependence on biomass energy and limited involvement of women and youth in WCA activities.

The major threats to water towers are degradation, change in land use and unsustainable management practices (KFWG and DRSRS, 2009). Degradation has resulted in reduced water supply making Kenya to be classified as water scarce country, with water endowment at 400 m^3 per capita, which is far below the global UN benchmark of 1000 m^3 per capital (MEMR (2012). By year 2012, the water supply in Nairobi was 580,000 m^3 per day against a demand of 750,000 m^3/day. This demand was projected to increase to 860,000 m^3/day by 2017 and 1.2 million m^3/day by 2035, requiring large and sustained investments in expanding water supply to meet the growing water needs (Nairobi Water Master plan, 2012). Many dams and water-pans were dug to supply water for farming, domestic and industrial use at independence. Over time, these have become degraded, silted and even inhabited. Rapid population growth has exerted immense pressure on the quality and quantity of water (Ministry of Environment and Mineral Resources, 2012). Provision of adequate water to Nairobi residents calls for concerted efforts to increase the water sources by maintaining existing sources while opening new ones.

To ensure sustainable conservation of water catchments areas, it’s important to link the providers of environmental goods and services with the users. Payment for Ecosystem services (PES) which is the practice of proposing incentives to farmers/landowners or protected area managers in exchange for managing their land or resources, in exchange to providing some environmental service, provide this vital link (MEMR, 2012). The recently launched National Forest Program identified opportunity to apply PES schemes to protect and conserve forest ecosystems noting that government institutions have responsibility to promote PES and support partnerships as well as ensure enabling legal framework is in place (Ministry of Environment and Natural Resources, 2016).

Objectives

i. Find out the willingness of the downstream buyers to pay for watershed protection services and socio-economic factors influencing their ability.
ii. Identify socio-economic issues influencing the willingness of the downstream buyers to pay for watershed protection.

Methods

Study Area

The study was carried out in the areas designated as catchment areas for Ndaka-ini dam which is located in Gatanga and Maragua districts, Murang’a County as shown in Figure 1. Gatanga District lies in longitude 36^o 44’ 39.46” E and 37^o 00’ 58.03” E and latitude 0^o 42’ 13.28” S and 1^o 01” 12.72” S. The altitude is 1,340 -2,190 metres above sea level. It is in agro ecological zones UH0, UH1, LM1, UM1 and UM2 (MoA, Gatanga District, 2010). Water catchment areas for the dam include the entire Sub- locations bordering the dam and those situated between the dam and the forest of which Kimakia and Gatare forests stations are covered.

The study area is about 80 km north of Nairobi and 40 km west of Thika town on the slopes of Aberdare forest at the tip of Thika and Maragua districts in Murang'a County. The Ndaka-ini dam's catchment area measures 75 square kilometres. It consists of Kimakia and Gatare Natural forests which form Aberdare Ranges. The main rivers that drain into the Dam from this catchment are Thika, Githika and Kayuyu. Thika drains 50 %, Githika 30 % and Kayuyu 20 % of the catchment into the Dam respectively (Athi Water Profile, 2015).

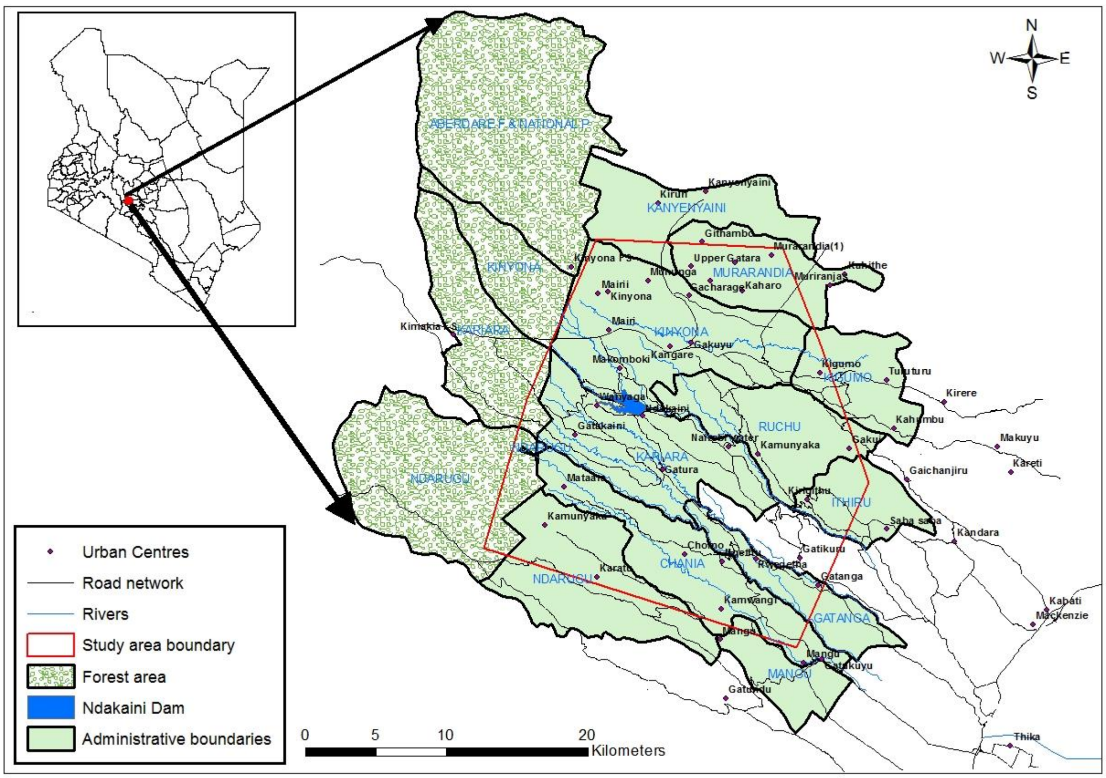

Figure 1. Location of the study area
Source: Kagombe and Kiama, (2012)

Sampling Design

Cluster sampling was used based on the data of water users that was obtained from Gatanga Water and Sewerage Company. The sampling frame was the number of water users supplied by Gatanga Water and Sewerage Company in the lower catchment of the dam. The data collection approach was adopted was from Waage et al., (2005) and Ruhweza and Wage (2002) whose main steps are: value chain approach to environmental service, demand analysis, contingent valuation to determine non-market ecosystem values, willingness to accept, cost-benefit analysis and benefit transfer methods. The key data collection methods include pre-testing of the questionnaire and make contacts with farmers, collection of secondary data on climate variables and socio-economic trends in the area. Primary and secondary data were collected. Primary data were obtained from the study sites by use of semi-structured interview schedule, questionnaire and Geographical Information System (GIS). Primary data included; socio-economics household information, land use changes, conservation activities, willingness to adopt conservation practices, willingness to pay for ES, institutional and legal framework for PES.

Interviews were administered to land users and foresters in the dam catchments area, water users, key informants, managers of institutions supplying water, large consumers of water, and water treatment companies. The issues captured for consumer included: socio-economic household data that affect economic decision, quantity of water consumed per household, alternative water sources, reliability of water source, quality of water, relation of water supply and conservation activities and willingness of the water user to pay for conservation of watershed.

Secondary data was collected from reports, books, public records, data sets held by institutions. These included; rainfall trends, intake and outtake of water in the dam, physical planning, on-farm tree planting, infrastructure growth, community structures, livelihood options for the farmers, policy and legal frameworks, household characteristics, history of the dam, trends of water use by consumers and challenges in water provision.

Results and discussion

Demographic characteristics of Water Consumers

Water consumers included individual households and large institutions within and around Thika town. Out of the 339 water consumers interviewed, 59 % were males and 41 % were females.
A study by Grafton *et al.*, (2009) have shown that household characteristics that include the number of people in the household (adults and children), size of household, level of education and household income has statistically significant and positive effects on household water consumption.

Conservation of Watersheds and willingness of Water Consumers to Pay for Management of Watershed

The first objective of the study was to find out whether downstream water consumers were able to link water they consumed to conservation of watersheds and their willingness to pay for management of watersheds. To address this objective, study respondents were asked to indicate main sources of water for household use. Table 1 shows water consumers' responses on the main sources of water for households use.

Table 1. Main sources of water for household use in Lower catchment of Ndaka-ini

Sources of water	N	Percent
Tapped water	116	34.2
Borehole	93	27.4
River/streams	73	21.5
Shallow well	33	9.7
Rain water	24	7.1
Total	**339**	**100.0**

As shown in Table 2 34.2 %, water consumers used tapped water in their homes; 27.4 % used borehole, 21.5 % used river/streams while 7.1 % used rain water. This implied that most of the households in the lower catchment Ndaka-ini were not supplied with tapped water. As a result, significant proportions of them opted to use ground water sources such as boreholes, shallow well and stream water. It further emerged that in some areas where good quality water was lacking, farmers harvested rain water for domestic use. The study sought to determine whether consumers with piped/tapped water were aware of the sources of water supplied in their homesteads. In response, 98.3 % reported that they were aware as shown in Figure 2.

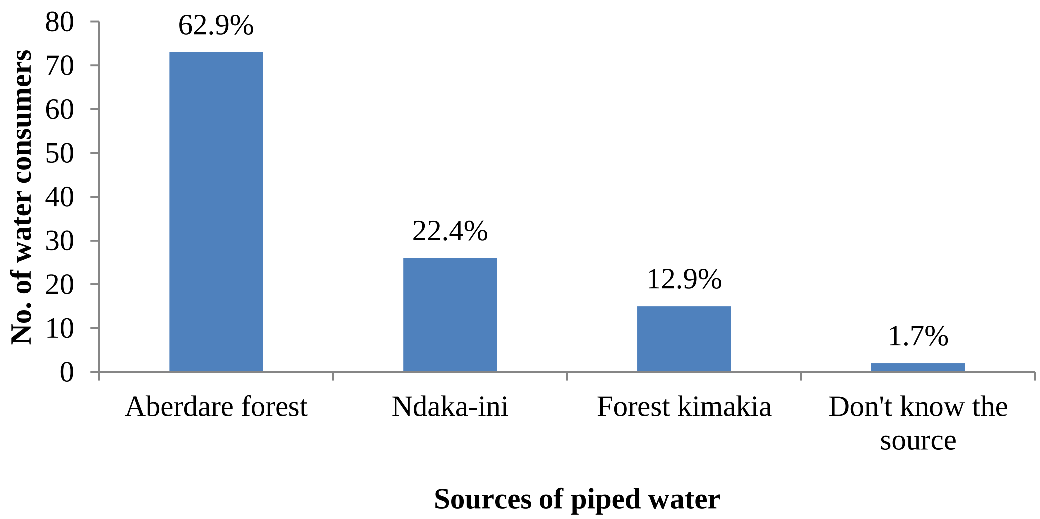

Figure 2. Sources of piped water for consumers in lower parts of Ndaka-ini dam

The study sought to know regularity of water supplied to the household. Table 3 shows consumers' responses on frequency of water supplied to their homesteads.

Table 2. Frequency of water supplied to consumers in lower parts of Ndaka-ini dam

Water supply	n	Percent
Everyday	8	6.9
Once per week	38	32.8
2 days per week	25	21.6
Once per month	33	28.4
3 days per month	12	10.3
Total	**116**	**100.0**

Table 2 shows that 32.8 % got water once per week, 28.4 % had water once per month, 21.6 % were supplied with water two days a week, and 10.3 % three days per month while 6.9 % water consumers were supplied with water every day. This implied that most households were not frequently supplied with water resulting to them exploring alternative sources. Irregular supply could be associated with shortage of water from catchment areas, high population of water consumers in the community and also poor water supply management.

To establish respondents' level of awareness on water supply information, the researcher asked respondents to indicate whether there was a link between water supplied in their homesteads and conservation of water sources. In response, 58.6 % consumers confirmed that there was a link while 41.4 % consumers felt that there was no link between the two. Further, those who indicated there was a link gave details of the connection of household water and conservation as in Table 3.

Table 3. Connection of household water and water source conservation in lower parts of Ndaka-ini dam

Link	n	Percent
Tree planting	22	19.0
Aberdare forest	16	13.8
Water catchment conservation	15	12.9
Riparian area conservation	11	9.5
Farming systems	4	3.4
No link	48	41.4
Total	**116**	**100.0**

Table 4 shows that 19.0 % of the consumers indicated that the link between water supply and water source conservations was through tree planting Results showed that 41.4 % of respondents had no link between water and conservation activity. This could have adverse effect on any conservation linked efforts as they may not support such activity. Awareness creation on payment for ecosystem service will provide this vital link to enable households to appreciate that positive conservation activity can lead to improved water services. A review of operation of water fund showed that one way of achieving long term protection of watershed is ensuring good conservation management and providing incentives sufficient to discourage further encroachment on and degradation of natural ecosystems (Rebecca *et al*., 2012). The study sought to know threats to conservation of water catchment areas. Table 4 shows consumers' responses on threats at water catchment areas.

Table 4. Response to consumers' in lower parts of Ndaka-ini on threats to water catchment areas

Threats to water catchment areas	N	Percent
Unfriendly trees	29	25.0
Climate change	19	16.4
Drought	15	12.9
Deforestation	14	12.1
Riparian cultivation	12	10.3
Lack of awareness	12	10.3
Poor farming practices	6	5.2
Land size	4	3.4
Pollution	3	2.6
Policies	2	1.7
Total	**116**	**100.0**

As shown in Table 5, 25.0 % of the water consumers reported that major challenge faced at water catchment areas was environment unfriendly tree species like *Eucalyptus* that led to drying up of water catchment areas. It also led to reduction of aquatic organisms that depend on critical thresholds of water (Dugan *et al*., 2010). Irregular climatic change was another threat that was reported by most farmers. According to 16.4 % of the water consumers, climatic change threatens the survival of species and the integrity of ecosystem. For instance, global warming has led to increased rainfall in some areas, with others experiencing severe droughts. An increasing frequency of climate extremes like floods and drought is aggravating the state of the available freshwater resources. Furthermore, two similar proportions (10.3 %) of the respondents indicated that cultivation of riparian areas and lack of awareness among farmers, were other major threats at water catchment areas respectively. This implied that lack of awareness among the community members on importance of conservation of catchment areas negatively influenced farmers' utilization of watershed resources. In an attempt to probe acceptable amount of cash incentive, farmers were required to indicate levels of incentives that would make them take PES initiative as shown in Table 5.

Table 5. Amount farmers were willing to be compensated to participate in the PES scheme in Ndaka-ini

Amount compensated	Yes		No		Not applicable	
	n	**%**	**n**	**%**	**n**	**%**
KES 5, 000	0	0.0	279	82.8	58	17.2
KES 10, 000	13	3.9	266	78.9	58	17.2
KES 20, 000	21	6.2	258	76.6	58	17.2

Table 5 shows the amount of money farmers would like to be compensated in order to participate in the scheme. All the farmers who were willing to participate in the scheme reported that they would not participate if compensated KES 5,000 per year. However, 3.9 % farmers reported that they would participate if compensated 10, 000 while 6.2 % farmers indicated that they would participate if compensated KES 20,000. This showed that the amounts of money farmers were compensated had a great impact towards their willingness to participate in the scheme. This related to the annual income of households in the area who are predominantly in tea farming which gives high returns. A similar study conducted in Nairobi showed the mean WTP was about KES 275 per month, approximately equivalent to US$3. This was almost 25 % of the average survey household's monthly water bill. This apparently large WTP value reflected the extent of water shortages in the survey area and people's preferences to pay for reliable water supply. The study showed a wide variation households' water bills (from KES. 120 -900 i.e., approximately from US$ 1.5 to 11.25 per month) and likewise a wide variation in WTP (Balana and Catacutan, 2012). Farmers were more willing to accept rewards in kind as shown in Table 6.

Table 6. Incentives farmers were willing to take to participate in conservation in Ndaka-ini

Reward system	n	Percent
Water supply	161	47.8
Carbon credit	37	11.0
Power supply	36	10.7
Firewood provision	33	9.8
Tree seedlings	26	7.7
Fodder provision	23	6.8
Water pumps and storage tanks	21	6.2
Total	**337**	**100.0**

Table 6 shows proposed reward system that gives farmers incentives to participate in conservation activities. Majority (47.8 %) of the farmers reported that provision of water supply could influence their participation in water conservation activities, 11.0 % indicated carbon credit while 10.7 % indicated power supply. Other reward systems mentioned included water pumps and storage tanks, fodder provision, tree seedlings and firewood supply. The type of reward was consistent with earlier baseline information that showed that most of farmers around the dam were not connected with tapped water.

Large-scale Water Users

Among the 30 large-scale water users sampled in Thika, 46.7 % were industries, 16.7 % were educational institutions, 16.7 % were catering providers, 10.0 % were health institutions and 10 % were rental units. All the institutions were supplied with tapped water. Table 7 shows average water bill per institution.

Table 7. Average Water Bill per Month for Institutions within Thika

Amount in KES.	Frequency	Percent
5001 to 50,000	16	53.3
50,000 to 100,000	6	20.0
100,001 to 150,000	2	6.7
150,001 to 250,000	6	20.0
Total	**30**	**100.0**

Results as shown in Table 7 indicate that most (53.3 %) of the institutions were paying an average bill of KES. 5,001 to 50,000 per month while an additional 20 % were paying between 50,000 to 100,000 per month. Water bill paid by an institution could be an indicator of their dependence on water source and their likelihood to support conservation effort in the catchment areas. The managers of institutions further reported that there was a link between the quantities of water supplied to conservation activities as shown in Table 8. Main link was bills they received for water supplied and tree planting/reforestation activities. The other link was conservation of water catchment areas (20.1 %) and afforestation (20 %) followed by creating awareness on good water conservation activities and efficient use of water resources. This provides a leeway for PES as conservation and tree planting activities that contribute to 40.1 % could be tied to the incentive provided through payment of water bills.

Table 8. Link between Water Supplied in the Institution to Conservation of Water Sources

	Frequency	Percent
Paying bills	10	33.3
Afforestation/ planting of trees	6	20.0
Better conservation of water catchment areas	6	20.1
Efficient use of water resources	2	6.7
Awareness	2	6.7
Total	**30**	**100.0**

These links could build a case for the conditions that may be attached to PES as they are likely to influence the water institutions in supporting conservation practices. The users of water services are likely to support incentives aimed at sustaining and/or strengthening an identified link. While a third of the users could connect water supplied with water bills, the other two thirds indicated a connection of water supplied to conservation efforts. This means that activities aimed at improving conservation would be welcome by consumers. The managers of the institutions indicated that there are major threats to water catchment areas as shown in Table 9.

Table 9. Institutions Perception on Threats to Ndaka-ini Water Catchment Areas

Threats	Frequency	Percent
Pollution	9	30.0
Mis-management of farms	6	20.0
Deforestation and forest encroachment	6	20.0
Climate change	4	13.3
Ignorance	2	6.7
Illegal water connections	2	6.7
Land use change	1	3.3
Total	**30**	**100.0**

As shown in Table 9, the respondents indicated that the main threats to water catchment areas were; pollution (30 %), mis-management of farms (20 %) and deforestation and forest encroachment (20 %). This indicates that there are areas PES could intervene to improve the catchment areas. All the managers agreed that they had a role to play in order to improve water supply in the institutions and also contribute towards conservation activities. The response from managers reflected challenges faced by water catchment water catchment areas as contained in Water Masteplan that include: Land degradation and soil erosion, poor management of water resources, water insecurity, poor waste management, and livelihood insecurity stemming from land degradation of water catchment areas among other (MENR, 2012).

The institutions were willing to provide incentives towards conservation of water sources as shown in Figure 3.

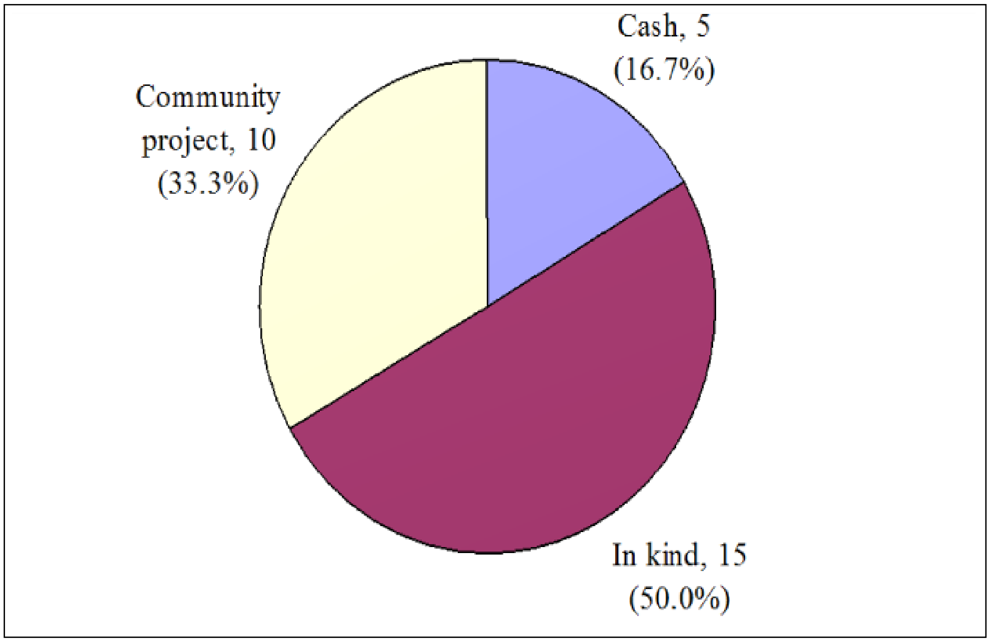

Figure 3. Types of incentives managers are willing to give to support conservation activities in Ndaka-ini

Among the 30 managers who took part in the study, 50.0 % were willing to offer support in kind, 33.3 % were willing to support community project while 16.7 % were willing to give cash. Further enquiry showed that cash of incentives managers were willing to provide per month varied from KES. 1000 to 200,000 as shown in Table 10.

Table 10. Cash incentives managers in Thika were willing to give to support conservation

Amount in KES. Per month	Frequency	Percent
1000 to 10,000	8	26.7
10,001 to 30,000	16	53.3
30,001 to 50,000	1	3.3
50,001 to 75,000	3	10.0
150,001 to 200,000	2	6.7
Total	**30**	**100.0**

As shown in Table 10, over 50.0 % of the managers were willing to offer over KES. 10,000 per month to support water conservation activities. In return to supporting conservation activities, the institutions attached conditions as shown in Table 11.

Table 11. Condition attached to incentive by main water users in Thika

Condition	Frequency	Percent
Conservation efforts	13	43.3
Constant water supply	8	26.6
Collective responsibility	6	20.0
Maintain planted trees	2	6.7
Reduction in water bills	1	3.3
Total	**30**	**100.0**

As shown in Table 11 the main conditions managers were attaching to the incentives they were willing to provide were to see efforts put in place for water conservation activities (43.3 %), having constant water supply (26.6 %) and the collective responsibility of the water consumers (20.0 %). Conditions attached were in line with enhancing conservation and improving water supply. Study conducted in East Usambara showed that there was a trade-off between the conditionality level and payment required to encourage participation (Karczan *et al*., 2012).

Economic Incentives Provided by Consumers to Farmers in Support of Watershed Protection

The second study objective was to find out economic incentives provided by the consumers to farmers in support of watershed protection. To respond to this objective, water consumers were asked to indicate whether they were willing to support conservation activities. In response, all (100.0 %) respondents reported that they were ready to offer their support in order to ensure there is continued water supply in homesteads. Figure 4 illustrates incentives given to support conservation activities.

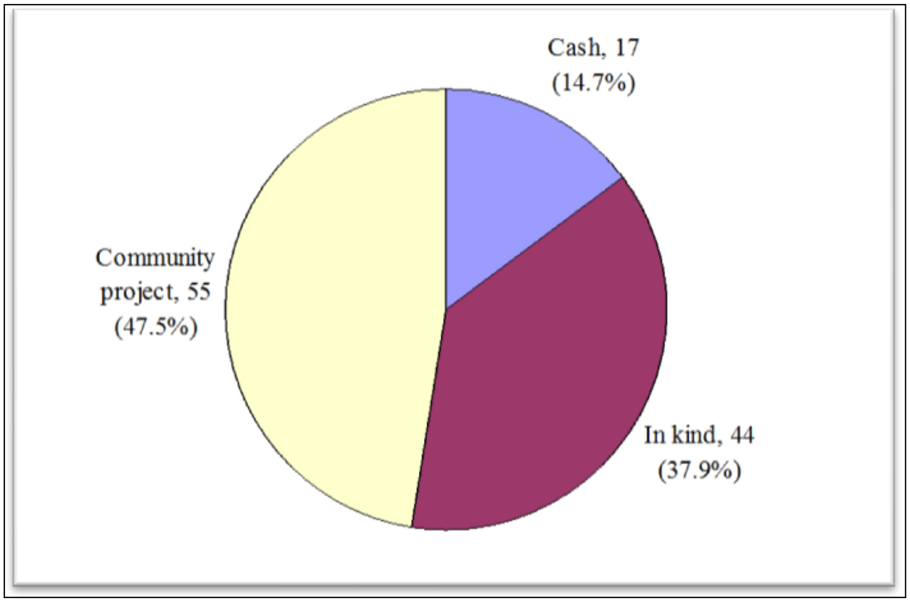

Figure 4. Incentives given to support conservation activities by consumers in Gatanga

As shown in figure 4, 47.5 % water consumers supported community projects, 37.9 % offered in kind support whereas 14.7 % consumers offered their support through giving out money. Table 12 shows the amount of financial support users of the water service were willing to provide.

Table 12. Financial support consumers are willing to give in Gatanga sub County

Amount per month	n	Percent
50 to 100	18	15.5
101 to 300	34	29.3
301to 500	1	0.9
Never support	63	54.3
Total	**116**	**100.0**

As shown in Table 12, 15.5 % consumers reported that they could support conservation activities by paying KES 50-100 per month, 29.3 % supported by paying KES 101-300 monthly while 0.9 % consumer indicated KES 301-500. However, 54.3 % consumers never supported conservation activities. his shows that less than half of the respondents were willing to pay the amount specified for watershed protection. Further analysis revealed a relationship between the amounts of money farmers are willing to give in support of conservation activity to the main source of household water as shown in Table 13.

Table 13. Main sources of water for household use and amount of money water consumers are willing to give to support conservation activities

Main sources of water	Amount of money willing to give to support conservation activities in KES.				Total	Chi-square statistics
	None	50 - 100	101 - 300	301 - 500		
Rain water	16	2	5	1	24	χ^2=103.719
River/streams	45	18	10	0	73	
Tapped water	9	31	67	9	116	
Borehole	54	17	22	0	93	df =12
Shallow well	18	8	7	0	33	
Total	142	76	111	10	339	Sig.=0.000*

***Significant at *p*<0.05 level

As shown in Table 13, results revealed that there was a significant relationship between farmers' sources of water and the amount of money they were willing to give to support conservation activities (χ^2=103.719, df=12, p=0.000). In particular, among the 24 farmers who harvested rain water for domestic use, 16 were not willing to support conservation activities, 2 reported that they would support with KES. 50-100, 5 would support with KES. 101 to 300, with only 1 indicating KES 301 to 500. Among the 116 with tapped water, majority (67) of them reported that they would support with KES 101 to 300. This shows that farmers with tapped water were more likely to support conservation activities compared to those whose sources of water were rain, river/streams, borehole and shallow well. Similar study conducted in Sasumua showed that water users in Nairobi were willing to pay an incremental US$1.25 over their normal water tariff to support conservation activities (FAO, 2013(a)). Consumers of water who were willing to give incentives in support of conservation activities attached conditions for their support as shown in Table 14.

Table 14. Conditions attached to incentive provided by consumers in Gatanga Sub-County

Conditions attached to incentives	n	Percent
Clean water	15	12.9
Regular water supply	22	19.0
Irrigation water	11	9.5
Alternative water projects	5	4.3
Not applicable	63	54.3
Total	**116**	**100.0**

Table 14 shows that 19.0 % stated that they would support conservation activity in return to regular water supply, 12.9 % gave clean water at their homesteads as condition, whereas 9.5% of consumers preferred irrigation water projects. A key aspect of PES is the extent of conditionality as it is the main key differentiating feature between PES and other non-coercive conservation approaches such as integrated conservation, development projects, and community based natural resource management (Ferraro and Kiss, 2002). However conditionality can be applied at different levels. Van Noordwijk and Leimona (2010) defined conditionality on a spectrum, where payment can be linked to (1) the consequence of an improved ecosystem service (for example, cleaner water), (2) improved system performance (for example, increased tree cover), (3) improved actions (for example, replanting in the runoff zone), (4) improved management plans (for example, an intent to replant in the runoff zone), or (5) improved management objectives. Choosing the extent of conditionality required to deliver fully the required ecosystem service at the least cost to farmers is an important component of PES design. The merits of conditionality are clear: it ensures service provision or, alternatively, avoids wasting resources by paying 'money for nothing' (Ferraro and Pattanayak, 2006), and it ensures that the practices paid for generate net benefits for users, as presumably the latter would otherwise not be willing to purchase those services at the given price

On the other hand, among the 54.3 % water consumers who reported that they never supported conservation activities, 45.7 % indicated that the major factor which hindered them was lack of finances whereas 8.6 % reported that services offered were very poor. Table 15 illustrates group incentives household heads are willing to participate in conservation activities.

Table 15. Group incentives identified by consumers in Gatanga

Group incentives	**n**	**Percent**
Improvement in road network	29	8.6
Putting up of schools	54	16.0
Provision of tapped water	88	26.1
Improve on health facility	56	16.6
Electricity provision	56	16.6
Capacity building	24	7.1
Provision of seedlings	30	8.9
Total	**337**	**100.0**

Table 16 shows group incentives households would engage in in return to conservation. Results showed that 8.6 % households identified improvement of the road network, 26.1 % provision of tapped water, 16.6 % activities that would improve health facility and 16.6 % capacity building and 8.9 % households were willing to participate in provision of seedlings.

Figure 6 shows the type of incentive farmers expect in order for them to participate in PES. Water provision was rated highest followed by firewood supply, power supply and carbon credit. Despite the catchment being the source of water for Nairobi, the community is still under supplied with water showing an inequity in natural resource distribution. This negatively affects the community view of the dam and so more efforts aimed at enhancing incentive is required in the area. As a result, the most preferred individual and group reward incentive was provision of water. The main group incentives were provision of tapped water as shown in Figure 4.20. The other group incentives preferred were schools, health facilities, supply of electricity, capacity building, improved road network and provision of seedling. There is need to balance individual and group incentives as both are key to conservation. The results compare well with a recent study which showed that the most preferred reward system were in kind and an emerging paradigm shift towards co-investment instead of payment (Namirembe *et al*., 2014). Co-investment would bridge the gap in rewards given that it's difficult to drive PES using contributions from consumers alone as they are far below the opportunity cost of the producer. Lessons from Naivasha was that PES has potential to be used as a vehicle to create local markets for environmental good through contribution of high value fruit trees and fodder crops that has led to improved livelihoods for the WRUA and farmers these areas. The additional income through improved farm production were more than what farmers received directly as incentive in PES (FAO, 2013b).

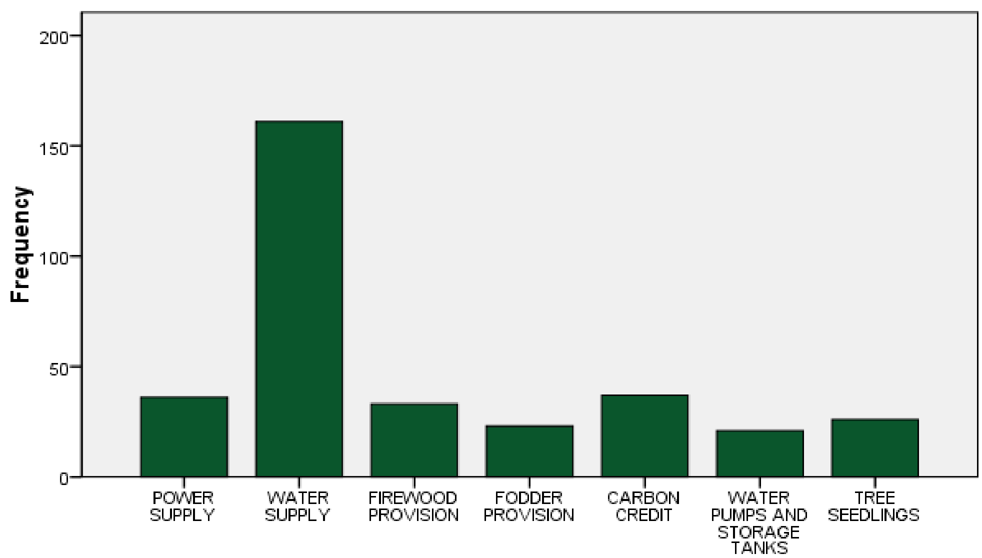

Figure 6. Proposed reward system to participate in conservation in Ndaka-ini

Studies conducted in Naivasha showed that farmers wanted to see direct benefits from their own efforts, not just hearing about how conservation is important to the wider area, or to downstream stakeholders. The economic case for conservation should be used to promote more sustainable farming practices (carrots instead of sticks). Roger and Risk (2012) noted that extension agents and NGOs need to think about how they communicate the conservation message to farmers as it may be more effective to talk with farmers about 'boosting production through good practices', than about conservation especially when initially conservational benefits are not clearly understood and a loss of productive land may be feared. This is the case for Ndaka-ini where more efforts should be put to direct benefits for farmers that can in return give them motivation to support conservation activities. The type of incentive is likely to be influenced by the income level of the household and this led to assessment of net income levels of the respondent as shown in Table 16.

Table 16. Net income generated by the farmers through cropping activities and livestock products

Net **income through cropping activities**	**Farmers' net income through livestock products in KES.**									**Total**
	20,000 to 50,000	50,001 to 100,000	100,001 to 150,000	150,001 to 200,000	200,000 to 300,000	300,001 to 400,000	400,001 to 500,000	500,000 and above	None	
20,000 to 50,000	3	0	0	0	1	0	0	0	10	14
50,001 to 100,000	2	8	4	1	4	0	0	0	11	30
100,001 to-150,000	12	6	12	9	3	1	1	0	18	62
150,001 to 200,000	13	12	9	11	2	8	0	2	14	71
200,000 to 300,000	7	3	7	6	2	5	0	2	10	42
300,001 to 400,000	4	4	12	9	2	2	0	4	7	44
400,001 to 500,000	6	3	6	6	2	3	0	5	6	37
500,000 and above	5	4	11	4	1	0	1	0	7	33
None	0	0	0	1	0	0	0	0	3	4
Total	**52**	**40**	**61**	**47**	**17**	**19**	**2**	**13**	**86**	**337**

$\chi^2 = 97.356$, df = 64, Sig. = 0.005* (Measured at $p<0.05$ level of significance)

As indicated in Table 16, in the last 12 months, 4.2 % respondents had a net income of KES20, 000 to 50, 000 in the cropping activities, 21.1 % had a net income of KES 150,001 to 200,000, 13.1 % had an income of KES 300,001 to 400,000 while 9.8% made an income of KES 500,000 and above. In relation to livestock activities, 15.4 % respondents made an income of KES 20,000 to 50,000, 18.1 % made an income of KES 100,001 to 150,000, 5.6 % made a net income of KES 300,001to 400,000 while 3.9 % made an income of KES 500,000 and above.

Chi-square test results revealed that there were significant differences among the farmers' level of income generated through cropping activities and livestock product per year (χ^2=97.356, df=64, p=0.005). The findings showed that while majority of the farmers were getting a net income ranging from KES. 20,0000 to 200,000 from livestock products, most of those engaging in cropping activities were getting a net income of KES. 100,000 to 400,000 as shown in Table 17.

Table 17. Farmers' net income from off farm sources and other sources in Gatanga

Net income (KES)	**Off farm sources**		**Other sources**	
	n	%	n	%
1,000 to 5,000	27	8.0	30	8.9
5,001 to 10,000	31	9.2	17	5.0
10,001 to 15,000	18	5.3	18	5.3
15,001 to 20,000	20	5.9	5	1.5
20,001 to 30,000	13	3.9	8	2.4
30,001 to 40,000	7	2.1	0	0.0
40,001to 50,000	4	1.2	0	0.0
50,001 to 100,000	17	5.0	1	0.3
None	200	59.3	258	76.6
Total	**337**	**100.0**	**337**	**100.0**

As shown in Table 17, majority of the households did not get any net income from off farm sources and other sources (off farm sources (59.30 %) and other sources (76.6 %)). Among the few respondents who made net income, 8.0 % made a net income of KES 1,000 to5,000 from off farm sources, 5.9 % made an income of KES 15,001 to 20,000 whereas 5 % made a net income of KES 50,001 to 100,000. From other sources, 8.9 % household heads made a net income of

KES 1,000 to 5,000, and 5.3 % made KES 10,001 to 15,000, with only 0.3 % household head reporting that they made an income of KES 50,001 to 100,000. This calls for diversification of income sources.

Conclusions and recommendations

Conclusions

The first objective was to evaluate the willingness of downstream consumers to pay for watershed protection. Majority of consumers were willing to participate in a scheme aimed at providing incentives to upstream farmers. In conclusion, results showed a relationship between willingness of farmers to accept conservation activities in return to incentives provided. There was a significant relationship between the consumers source of water to the amount they were willing to give to conservation activities with farmers who were connected with water from the Ndaka-ini catchment willing to give more. In addition, large water consumers were willing to give incentives in conservation in return to being assured reliable water supply. However, there was no framework in which consumers willing to pay could use to provide incentives to the providers of environmental services. The study indicated that majority of respondents, both small-scale and large-scale water users were willing to pay additional fees that would go to conservation. The mechanism for such payment must be worked out jointly by the users, Water Company and WRSB. The second objective was to identify incentives consumers were willing to provide to farmers in return to improved conservation practices. In conclusion, the main incentives offered by users of water were in support of community projects (47 %), in kind (38 %) and in cash (15 %). There was a significant relationship between the source of water in the household and willingness to support conservation, with household with tapped water supply more willing to provide incentives. This relates well with providers of ES whose main preferred group incentive was provision of tapped water to the households.

Recommendations

Farmers Engagement: Engage farmers in PES using a combination incentives in-kind supported by a proportion of cash rewards. Conservation practices that should be sold out to farmers are terracing, contour farming, planting of grass-strips and planting bamboo along the rivers. Farmers' awareness towards conservation should be enhanced to improve uptake of PES packages. In addition, cost benefit analysis for adopting different conservation practices should be carried out.

Mechanism for passing on incentives: The collection point for the incentive would be through water bills charged by Water Company. To reach the supplier of the service, there would be need to develop a very clear mechanism on how the incentives will be passed over while also developing a monitoring system to ensure compliance. Experience from Brazil showed that payment was the most effective tool with 25 % of revenue being reinvested to support PES.

Types of incentives: Promote PES using existing rewards in conservation but reorganize them to include conditionality so as to gain the additionality out of the provided incentives. In addition, develop a framework for tapping incentives provided by users and another one for giving back to the providers. Where possible, promote bundled approach in ES as it's more cost effective.

Recommendation for Further Research: Further studies need to be conducted on mechanisms for financing PES, combining public and private sector inputs. Public financing modelled around the one for Brazil to be explored. In addition, develop mechanisms for pooling resources from the willing individuals and corporations ready to support PES that would go towards supporting a voluntary scheme. Further, National and County governments to set aside funds that would support PES implementation.

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From the Wild to Markets and Farmlands: Plant Species in Biotrade

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Abstract
Wild collection of plant products is an economic activity that serves subsistence needs but is increasingly becoming an income generating activity. The needs include food, fruits, gums, tubers, fibers, materials for construction and herbal medicine among others. Kenya's changing socio-economic landscape is shaping both producer and consumer ends of the market of wild-collected plants. This niche market, part of biotrade is sometimes construed to border on crime against wild plants because it is undocumented, largely unregulated and is barely accounted for economically. Market surveys were carried out in Kenyan border towns to document plant species in trade, products, volumes, sources, market players and associated challenges. Market survey results indicated widespread trade in plants locally, regionally or internationally. More than 100 flowering plant species were documented in trade in Kenyan markets, mainly wild-sourced and their various uses fairly widely accepted. Most are sourced from forest reserves, communal land and small holder farms. This trade is dominated by men and product knowledge derives heavily from indigenous knowledge. Plant species frequently in trade, are identified and prioritized for conservation and sustainable utilization. The declining wild sources call for strategies that ensure continuous supply, hence domestication, farm forestry and restoration on communal land and natural forests are proposed.

Key words: biotrade, ethno botany, conservation, indigenous knowledge

Introduction
The world's annual trade in pharmaceutical plants in 2011 was estimated to be worth about USD $ 2.2 B (Anon, 2015). These comprise some of 50,000 to 70,000 medicinal and aromatic plant species used in both conventional and traditional medicine. However, the exact volumes and species of plant materials in this trade remain unknown for most countries including Kenya. The

use of plants and their derivatives as medicine and food, to heal and cure diseases, or to improve health and wellbeing is widely acknowledged, including by the World Health Organization-WHO (WHO, 1978).The products derived from biodiversity and are in trade comprise biotrade. Most of it is legal trade, domiciled under Non-wood forest products (NWFPs). The products may be sourced sustainably from different types of forests (*in situ*) or through cultivation (*in domo*). These include plants for food, ornaments, instruments, timber, tourist souvenirs, perfumes and medicines. For Kenya, trade in medicinal plants and other NWFPs is an important part of biotrade.

Illegal wildlife trade is not new to Kenya, as the country has battled trade in ivory for decades. Kenya is home to more than 7,000 species of plants (Beentje, 1994) and recognizes the challenges associated with wild-collection of plants and the associated trade. Some 1,200 plant species are medicinal (Kokwaro, 1976; Gachathi, 1989; Johns and Kokwaro, 1991). Maundu *et al*., (1999) recorded more than 80 nutraceutical species (vegetables, pulses, fruits, stimulants, gums and resins) locally traded in parts of the country. Other, authors Dharani *et al*., (2010) have documented trees for management of Malaria an important tropical disease. In deed efforts, focusing on groups of species and ecosystems abound, including the Natural Capital Map (Western *et al.*, 2015). Research and management frameworks also exist including the proposal to establish centres to study specific groups such as medicinal plants (Odunga, 2013). However, Kenya lacks data on species and volumes of indigenous non-timber plants in trade and the effects of overharvesting. Efforts to conserve these equally useful plants remain futile until actual trades are documented and accurately reported. Accuracy is complicated by wildlife criminals and illegal traders who often disguise such plants as wood fuel, roots, bark, dried powders and other forms that are difficult to identify conventionally. Living plants are easily disguised by cutting off leaves which later regrow. Uncertainty also affects pre-processed materials e.g. gum from commercial Aloe species (Mukonyi *et al*., 2011). Lack of certainty makes it difficult for reporting licensed collection, harvesting and trade and on the downside, for law enforcement agents to document cases of crime against wild plants.

Second to loss of habitats, illegal trade can easily put species at the risk of extinction (Cunningham, 1996; Botha, *et al.,* 2004). The Convention on International Trade in Endangered Species of wild Flora and Fauna (CITES) is a conservation and trade treaty (Anon, 2018a; 2018b). Over 35,000 species of flora and fauna in trade are internationally protected under this treaty. CITES regulates international trade in the listed species, so that trade neither threatens their survival nor contributes to the current extinction crisis. Some 220 species of Kenyan plants are CITES-listed and they include Aloes (medicinal), orchids and Euphorbias (ornamentals) and medicinal tree species such as *Prunus Africana* (Hook.f.) Kalkm Rosaceae and *Osyris lanceolata* Hoechst Santalaceae-East African Sandalwood. Literature and media reports decry the unregulated harvesting of wild plants for trade as it easily transforms into international trade. Marshall (1998) noted an increase in trade in medicinal plants locally, regionally and internationally in response to the rapid urbanization and globalization. Kenya is rapidly undergoing urbanization and globalization. Urbanization is the growth of the urban proportion of the entire country's population (Hope, 2012). It moves migrants beyond their natural resources including natural forests and by concentrating them in urban areas; it creates niche markets and market intermediaries (Bodeker, 1997). The critical connections among the peoples persist through trade and cultural constructs such as the practice of traditional medicine. On the other hand, globalization has accelerates interchange among remote communities including researchers, investors, intermediaries and markets, by providing the critical feedback loop for all partners (Leontiand, 2013). Both trends have combined to greatly boost trade in and the practice of herbal medicine.

The aim of this study was to document plants and plant products in legal and illegal trade in Kenya, and to propose measures for their conservation and sustainable utilization. Species in biotrade could guide tree species selection for on-farm tree-planting schemes and enrichment planting in natural forests and on communal lands. Also, this data can guide research including for drug development (Botha *et al*, 2004). This paper therefore highlights plants in trade in Kenyan markets. It synthesizes attributes of some 22 species most mainly traded for medicine. These are of interest to the market and may be of interest in restoration, on-farm and community forestry and tree domestication

Materials and methods

Study sites

This study was conducted in Kenya in counties bordering Tanzania and Uganda, served by ports of entry/exit. Most have recently experienced emigration of youth to nearby urban centres, have some area under natural forest and previous studies indicate some level of biotrade. The data was collected from urban and peri-urban market centers in these counties. Specifically, these market centres are; Kibra, Kariakor, Ngara, Kawangware, Westlands, Lavington, Ngandu-Lenana, -Nairobi County, Dagoretti-Kikuyu County, Kakamega town-Kakamega County, Luanda and Mbale markets-Vihiga, Bungoma town, Mayanja, Kimilili-Bungoma County, Kitale town-Trans Nzoia County, Ngongmarket, Kiserian market, Ilbisil, Nguruman, Oloitoktok, Namanga-Kajiado county, Ntulele, Suswa, Naroktown, Oldonyo, Ntulele, Ewaso-Nyiro- Narok county, and Kapenguria-West Pokot County (Figure 1).

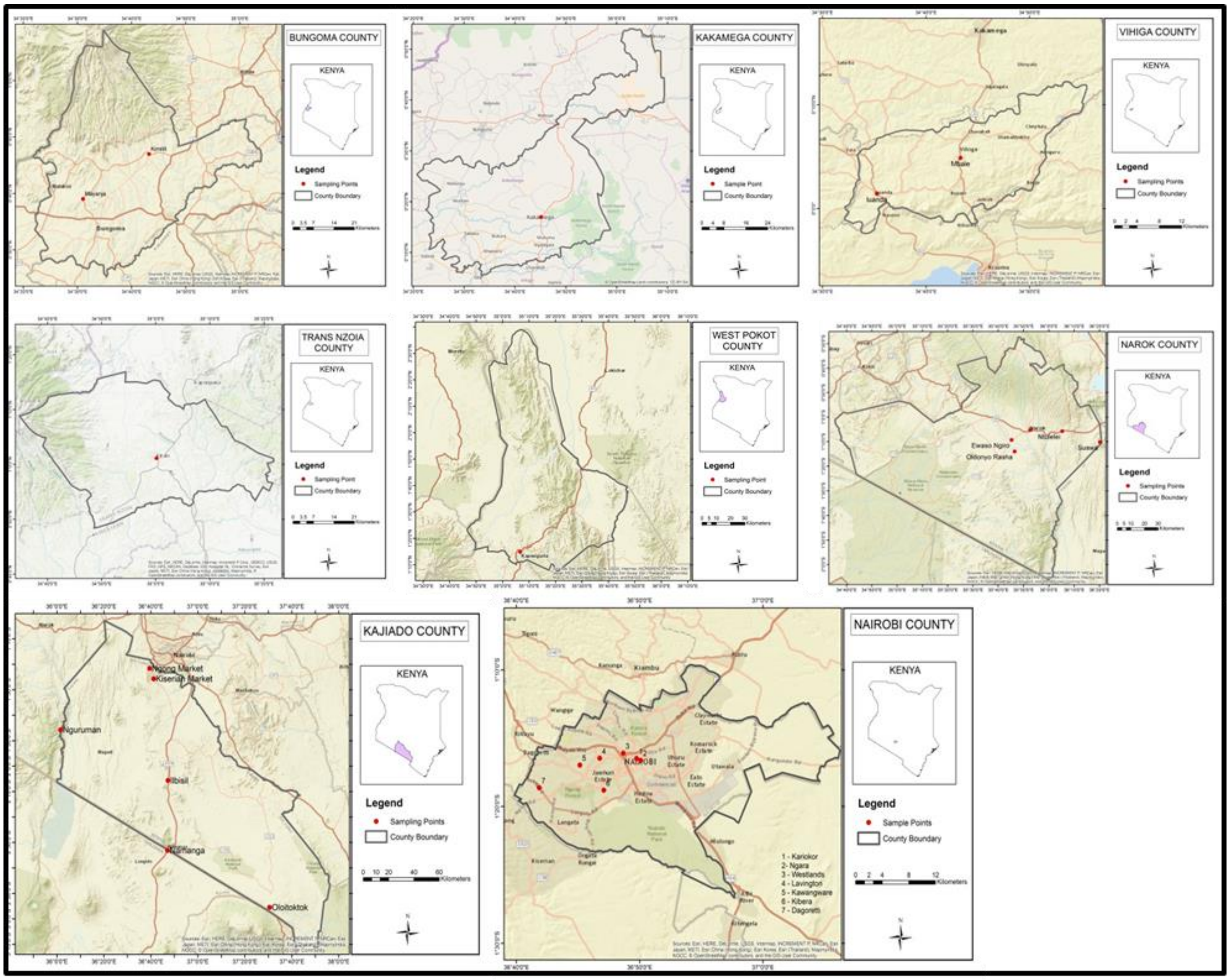

Figure1. Maps showing study sites

Collection of market data

Data was collected on the wild-collected plant species in trade in open air markets in the study area. The markets were visited on various dates between January 2016 and November 2017, to interview the vendors, nurserymen and women, traders, street vendors, collectors, retailers and herbalists. There are no crude estimates for these vendors in Kenya, therefore non-probability purposive sampling, incorporating aspects of snowball sampling were used (Denscombe, 2003). First, the interviewees were requested to sign a consent form, affirming their willingness to participate in the research. Data on plants in trade was collected by interviewing vendors of the plants/products at the open market centres as well as free listing and observation. Data recorded includes the biodata of the interviewee, their roles, plant products that they traded, customer base, markets, sources, quantities, pricing and general procurement of the products. The views of the vendors on the status of plants in the wild, impact of this trade on wild populations and their ideas for sustainable production were also recorded. The sampling targeted only the vendors practicing the trade and who could lead the interviewer to the next vendor. In some cases, interviews were facilitated by translators who knew and spoke the local language as well as English or Swahili very well.

Identification of plants and samples

The vernacular or local name and the part of the plant from which it was sourced were recorded. Samples for DNA analysis and bar-coding of the plant materials were collected from each vendor. These samples were labeled and sealed in ziplock bags and taken to the DNA laboratory at the National Museums of Kenya for verification. Herbarium specimens were identified with the help of parataxonomists, published literature floras (Kokwaro, 1976, Beentje, 1994; Agnew and Agnew 1994; 2010, Johns and Kokwaro, 1991; Gachathi, 1989, Maundu*et al*., 1999, Kokwaro, 2009; Prota4U, 2017) and the herbarium reference collection. The vernacular names of the plants in trade were translated to botanical names by a parataxonomist and were later confirmed using literature. At ports of exit/entry including airports, customs and Phytosanitary offices, confiscated and suspected contraband plant materials were recorded and subsampled for later identification using DNA techniques.

Data analysis

Data from the market survey was entered and analyzed using the Microsoft Office Excel. Frequency of medicinal plants by family and species were computed. Data was summarized in tables and charts as appropriate.

Results and discussion

Description of sample population

A total of 78 vendors participated in the survey, predominantly men (Figure 2.)

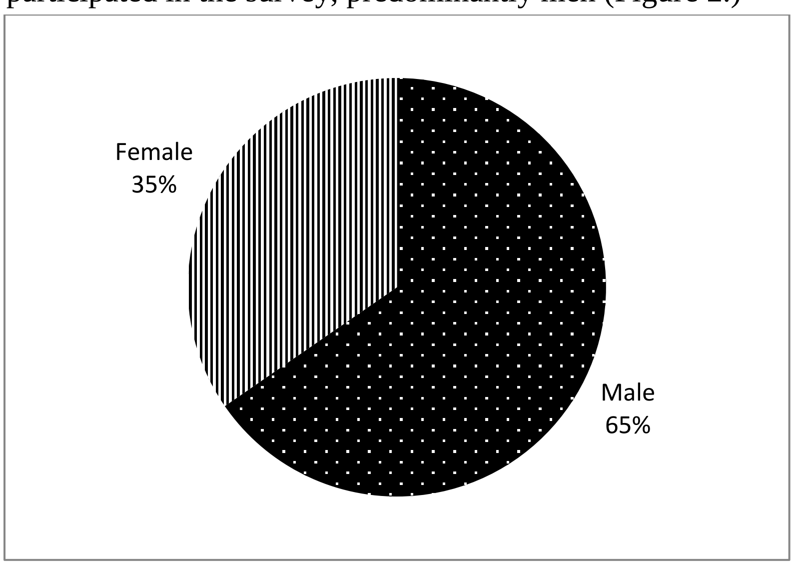

Figure 2. Segregation of interviewees by gender

The segregation of interviewees by level of education (Figure 3) reveals that most of the interviewees lacked elementary education 62 %.

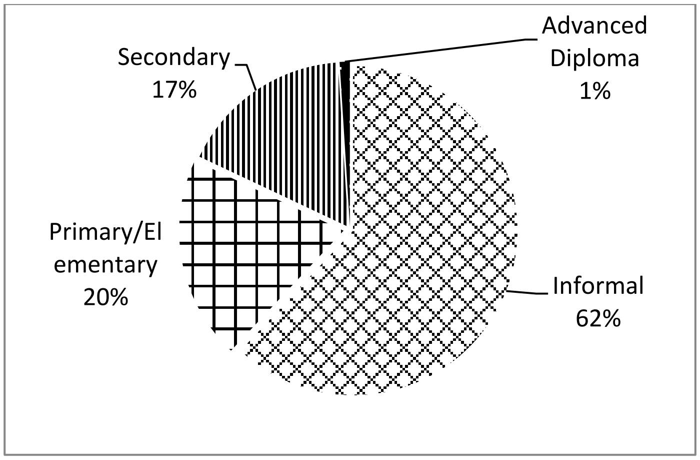

Figure 3. Level of education of vendors of plants and plant products

Motive for trading plants/plant products

Half (50 %) of the vendors interviewed were in the business for income generation while 46 % were exploiting their indigenous knowledge (IK) and skill acquired through apprenticeship (Figure 4).

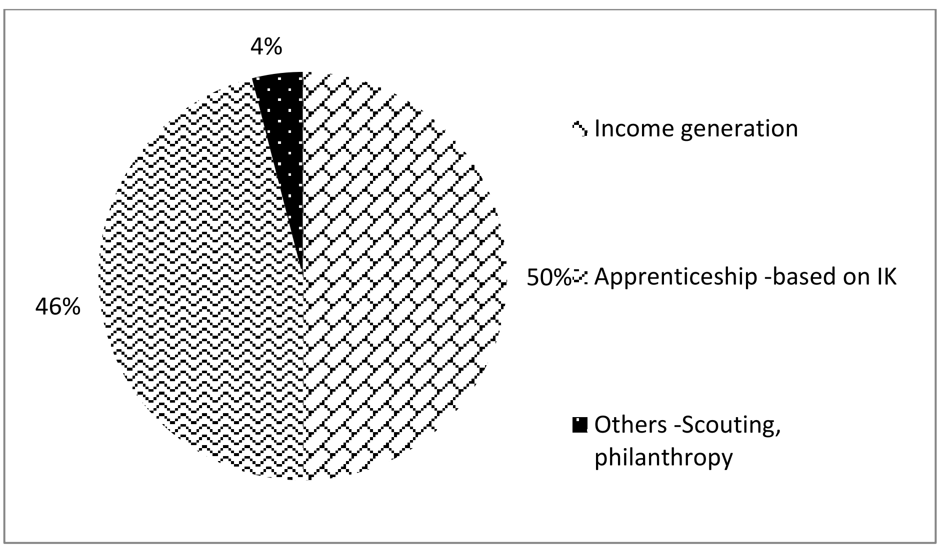

Figure 4. Factors influencing trade in plants/plant products

Sources of plants and plant products

Most vendors (89 %) indicated that their materials were sourced from the wild either by the individual vendors (46 %), or middlemen (23 %).Farmlands as outlets provided 2 % of the materials in trade (Figure 5).

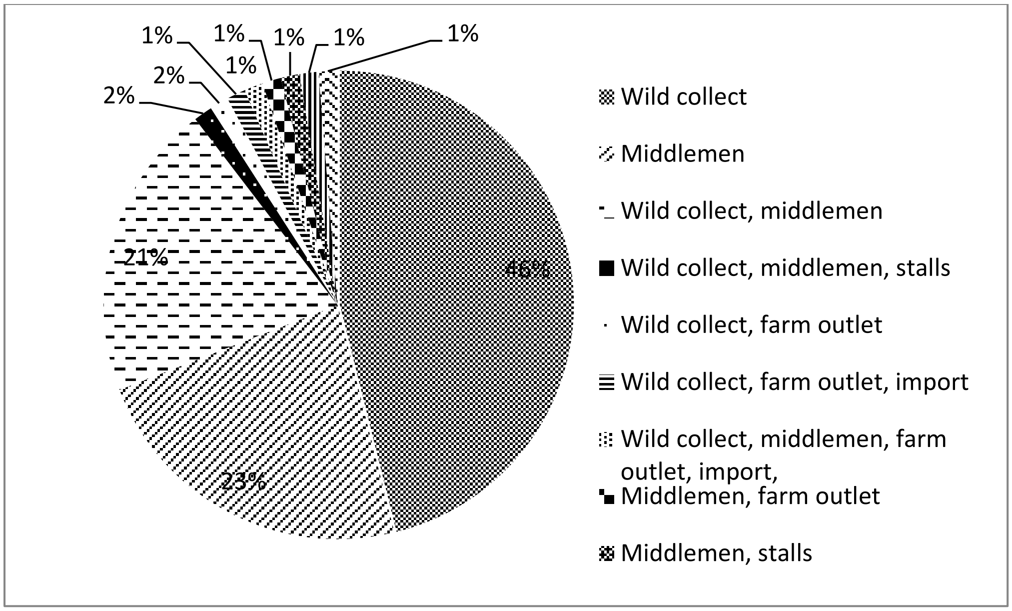

Figure 5. Sources of plants/ plant products in trade

Diversity of plant products in markets

Herbal medicine contributed the highest diversity of wild-source plants in trade) followed by living plants used in landscaping and planted in home gardens for other uses(Figure 6).

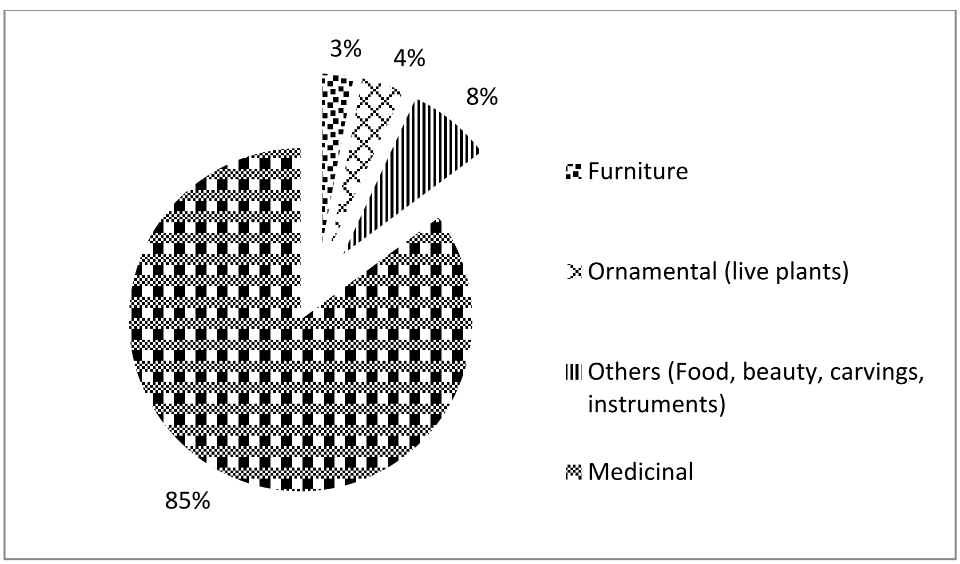

Figure 6. Plant species in trade by use category

Challenges of collecting plants from the wild

The challenges that the traders associated with their practice of collecting materials from the wild:distance (43 %) and availability (17 %) and licenses (8 % (Figure 7).

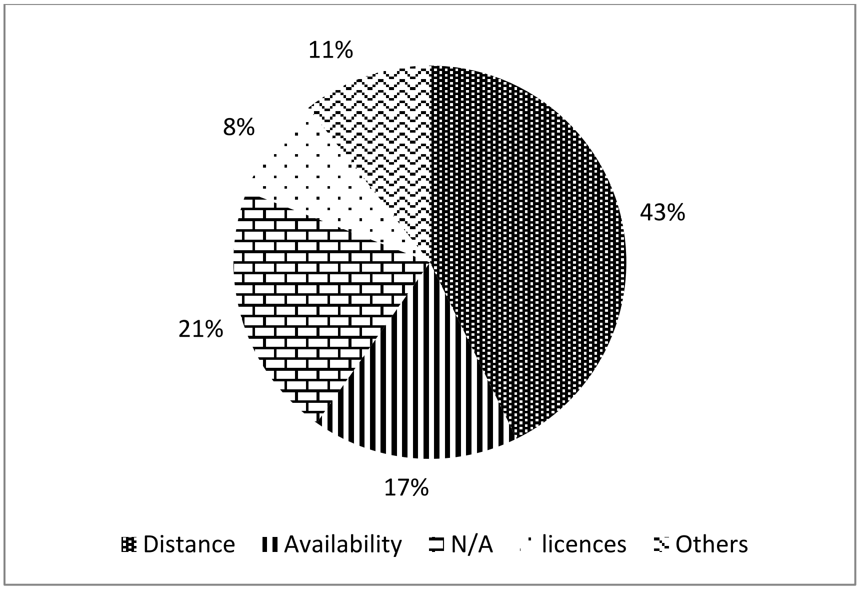

Figure 7. Challenges associated with collecting plant products from the wild

Plant species traded in the markets

More than 100 plant species were recorded in the markets survey. The species frequently in trade (at least 10 % of vendors) and identified to some level of certainty are shown in Figure 8.

The most frequently traded species belong to 17 plant families. Their frequency in trade is indicated, name, natural distribution, habit, habitat, uses and matching agro-climatic is as shown in Table 1.

Table 1. Frequently traded species proposed for forestry schemes

Market rank	Species (Family)	Distrib./ Flora reg.	Habit	Habitat preference	Uses-	Agro-climatic. zone
1	*Rhamnu sprinioides* (Rhamnaceae)	K13456	Shrub, Tree to 9m	Forest edges, rarely in secondary bushland	Med., L/s, Agrfor	IV, V, VII
2	*Rhamnus staddo* (Rhamnaceae)	K13456	Shrub or tree to 7.5m	Dry upland forest edges, secondary evergreen bushland, bushed grassland	Med. L/s	IV, V, VII
3	*Osyris lanceolata* (Santalaceae)	K123467	Shrub or Tree, to 6m	Forest margins, evergreen bushland, grassland, thickets, Rocky sites	Med., Dye, Fb, Fr.Fd, oil, L/s	I, II, VI, VII
4	*Warbugia ugandensis*	K3456	Tree to 30m,	Riverine forests, Dry upland forest,	T., Med.,Fd,	II, III, IV, V, VI

	(Canellaceae		evergreen	wooded grassland, Woodland (A.*xanthophloea*)	Glue, L/s, Agrfor	
5	*Acacia nilotica* (Mimosaceae)	K123467	Tree to 12m	Wooded grassland, *Acacia* grassland, open and clump bushland	Med., poles, Agrfor	I, II, VI, VII
6	*Pappe acapensis* (Sapindaceae)	K1234567	Shrub or tree 2-9m	Bushed or wooded grassland, rockysites, semi-evergreen bush/woodland	Med., Fr, Wood, L/s	I-VII
7	*Carissa edulis* (Apocynaceae)	K1234567	Shrub/ scrambler to 14m	Forest edge, bushland, grasslands, rocky places	Fd, Fr, Med. L/s, Agrfor	I-VII
8	*Clerodendrum myricoides* (Verbenaceae)	K1234567	Shrub to 3.5m	Dry or semi-evergreen bushland, wooded grassland, rocky sites	Med., L/s	I-VII
9	*Todalia asiatica* (Rutaceae)	K1234567	Shrub/ Liana	Forest margins, secondary regrowth, grassland thickets	Med.	I-VII
10	*Turraea mombasana* (Meliaceae)	K13467	Shrub to 3m	Dry forest (margins), semi-evergreen bushland	Med., L/s	III, IV, V,VI VII
11	*Albizia anthelmintica* (Mimosaceae)	K123467	Shrub or tree 3-7m	Dry bushland, on lava or along seasonal rivers, wooded or bushed grassland, coastal evergreen bushland	Med., Wood, Agrfor	II, IV, V, VI, VII
12	*Olea europaea Africana* (Oleaceae)	K1234567	Tree/ shrub evergreen to 24m	Dry upland evergreen forest, woodland	T, F/w, Med. Fr., Agrfor	I-VII
13	*Euclea divinorum* (Ebenaceae)	K1234567	Shrub or tree 1-9m evergreen	Dry forest (margins), riverine in bushland or forest, bushed, wooded grassland, bushland,	Med., L/s, Agrfor	I-VII

				pastureland weed		
14	*Embelia schimperi* (Myrsinaceae)	K3456	Shrub/ Climber	Upland evergreen forest	Med, Fd	II, III, IV, V, VI
15	*Myrsine melanophloeos* (Myrsinaceae)	K1234567	Tree evergreen t4.5-20m	Upland forest to edge of moorland	T, Med, L/	I-VII
16	*Ximenia Americana* (Olacaceae)	K1234567	Tree, Shrub to 6m	Coastal bushland, wooded grassland, dry woodland	T, Fr, Med., Oil, Agrfor	I-VII
17	*Zanthoxylum chalybeum* (Rutaceae)	K123457	Shrub or tree to 10	Semi-evergreen or dry bushland. Rocky sites, wooded grassland, dry forest, thickets	Med., L/s, Agrfor	I, III, IV, V, VI, VII
18	*Zanthoxylum usambarense* (Rutaceae)	K134567	Tree 2.5-15m	Dry forest or remnant clump thickets, secondary bushland	Med., L/s	II, III, IV, V, VI VII
19	*Trimeria grandifolia* (Flacourtiaceae)	K1234567	Shrub (scrambler) or tree to 12m	Dry evergreen forest, less often in moist or evergreen (clump) bushland	Med., L/s	I-VII
20	*Dovyalis abyssinica* (Flacourtiaceae)	K1234567	Shrub or tree to 13m	Upland moist or dry forest (edges), riverine, clump evergreen bushland	Med., L/s, Fr.	I-VII
21	*Strychno shenningsii*- (Loganiaceae)	K1234567	Shrub/ Tree to 12m	Dry forest, riverine, rocky hillsides	Med., L/s, Agrfor	I-VII
22	*Combretum molle* (Combretaceae)	K1234567	Tree to 8m	Wooded grassland, woodland, bushland/forest transition zone, in shallow rocky soils/hillsides/lava	Med., W/fuel, Agrfor	I-VII

Key to described uses: Dye, Fb-Fibre, Fr-Fruit, Fd-Food, L/s-Landscape, Med., -Medicinal, T-Timber, W/fuel-Woodfuel, Agrfor: Agroforestry species

Discussion

Vendors of plant and plant materials

Vendors of these products were predominantly men and similar studies have found male dominance in the biotrade (Kuipers, 1997). This finding differs from FAO (2014) which found that women generally rely more on NWFP for household use and income.The vendors generally had elementary or no education as shown.The harvesting of plant materials from the wild is a laborious activity which may explain why it isdominated by men.

Trading plants/plant products

Plants and plant products traded in markets play important role in individual and household incomes (Botha *et al*., 2004). Most vendors are in this trade for income, closely followed by those exploiting their IK. This trade therefore has a two-fold role- income generation and employment. Similar findings about NWFPs are cited in (Botha *et al.*, 2004; Tieguhong and Ndoye, 2004; Mbuvi and Boon, 2008).

Sources of plant materials

Vendors indicated overwhelming preference for trading in wild-sourced plant products. Medicinal plants are harvested from different wild habitats, including natural forests, woodlands, grasslands and riverine vegetation. Farmlands represent 2 % of the sources, meaning that as sources, they may become less domesticated or depleted of the materials or the land tenure prohibits free access (Mcmullin *et al*., (2012). The main product in this market is medicinal plants. Similar findings have been documented in research on medicinal plants in trade, in other parts of the world (Kuipers, 1997; FAO 2003, Mcmullin *et al*., 2012). Indeed markets have shown preference for wild-source materials claimed to be more potent, even though domestication and cultivation promise more sustainable production, to meet the growing local, regional and international markets.Wild-sources are noteasily or freely accessible due to long distance and low availability.. Some vendors said that they source these products from Uganda, Rwanda, South Sudan and even Congo, displaying the transnational nature of this trade as documented in FAO (2003); Tieguhong and Ndoye (2004).- somewhat pointing at the urgency for a regional approach to developing the framework for trading in these plant products.

Plant species in trade

Different plants and plant products are traded in Kenyan markets. The vendors predominantly use tribal names, for their products, making it easy to communicate among themselves and their customers. Local names perhaps reinforce consumer confidence, that the materials are indigenous, wild-sourced and that the vendors are sufficiently skilled in the tradeof practice However, the use of local names makes it difficult to record and regulate this trade and enforce legislation. Botha *et al*., (2004) noted a positive correlation between the number of plant species and markets with growing populations and higher ethnic diversity. Some 22 species were commonly traded (by more than 10 % of the vendors). Published reports indicate that most were previously widespread and growing naturally in different Kenyan habitats and ecosystems (Beentje, 1994). As such, they can be easily re-introduced into those areas to augment local biodiversity, or as part of on-farm forestry to support incomes through biotrade so long as they are cultivated in suitable habitats.

Projection of volumes of plant materials traded

In South Africa, about 60 % of the population was estimated to use some 750g of plant materials per person per year (Moeng and Potgieter, 2011). Presently, with a population of 58million, this translates to 26.1 tons of medicinal plant material. Although historical figures do not exist for Kenya, proximity and similar socio-economic characteristics point to the fact that the trend may be similar.

Biotrade and forest policy

Kenya's Forest policy 2007 (GOK, 2007) and the Forest Act, 2005 (GOK, 2005) and the Agriculture Act CAP 318 of 2009 (GOK, 2009) emphasized the need to develop farm forestry so as to increase forest cover, diversify subsistence production and incomes, while contributing to soil and water conservation. These legislations, though now revised provided a basis for the development of the biotrade sector. The Forest conservation and management Act, 2016 (GOK, 2016) spells out incentives from the government for increasing forest and tree cover including trade in forest products even from private forests. The current legislative framework is clear on the intention, but short on practical guidance for reaching the desired 10 % forest and tree cover in a way that also enables biotrade to flourish.

Conclusion and recommendations

Consideration of biotrade in choice of species already implies a wider range of native species. This calls for the forester, environmentalist and agricultural extension officers to provide additional information on more species, their ecological requirements and their sustainable management. Simple evidence-based methods that can support native species selection can facilitate afforestation at different scales (Lu *et al*., 2017). Special consideration for the farmers' economic realities Liyama *et al*., (2016) and elimination of socio-political disincentives Oeba *et al*., (2012) are also imperative. Overall, there is need to support farmers in silviculture of the species being proposed, their utilization, and information, quality planting materials market intelligence and marketing strategies.

The biotrade subsector in Kenya has great potential, as the plant resourcespreviously used at household level are now in trade,serving the demand of distant markets i.e. the urban poor and beyond. By and large, this enterprise, dealing in crude plant products, is contributing to micro- and macro-economic development. The following are recommendations to take this trade forward:

- At the technical level, there is need for well researched and simple, evidence-based methods for native species selection to support and facilitate local forest restoration and afforestation efforts including farm forestry.
- For research, there is need to replicate this study in other markets around the country, because market surveys provide data on local values and status of conservation of indigenous plants.
- There is need to take pressure off the wild sources of plants and to reduce challenges associated with collecting bioresources and domestication is perhaps the way to go. Providers need skills to navigate the markets while buyers should be sensitized on responsible sourcing as part of the environmental and ecological safeguards in this biosector.
- Therefore, a regulatory framework is required for this market to guide its growth and development..

Acknowledgements
We wish to acknowledge the USAID PEER plants project for the funding for fieldwork (under PEER cycle 4), NMK for institutional support throughout our time on the project, KFS and KWS as partners on the USAID PEER plants project and for facilitating access to the protected areas. Special thanks go to Mr. Henry Saitabau for translation, field and market guidance, Mr. Dickens Odeny for the maps. Dr. Isaac Misiko, Mr. Francis Kigen and other traders, for their valuable insights into the trade, pre-processing, wild collecting and use of the plant materials.

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Participatory Forest Management: A Case of Equity in the Forest Plantation Establishment and Livelihood Improvement Scheme in Gathiuru and Hombe Forests in Central Kenya

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Abstract

The study analyses equity in participatory plantation establishment and livelihood scheme (PELIS) formally known as *shamba* (farm) system in Gathiuru and Hombe forests in Kenya. This is done by determining annual inputs and outputs of three partners in PELIS including the Kenya Forest Service (KFS), three saw milling companies and the communities farming in Hombe and Gathiuru forests. The study uses Adams equity theory and applies the equity theory ratios as the basis of assessing equity under PELIS arrangements. Primary data was collected using questionnaires from 321 farmers participating in Gathiuru and Hombe Forests PELIS. By determining inputs into tree and agricultural crop production and subsequent benefits from the investments, the total community inputs and outputs into the program were calculated and the data analysis limited to a three-year period (2012 to 2014), which corresponds to the number of years farmers cultivate in one plot under the scheme. This was compared with annual inputs and outputs by KFS and three of the main timber companies trading within the same period. Equity ratio analysis based on annual average output: input ratios for KFS between 2012 to 2014 were 4.1:1; 2.6:1; and 3.1:1; for the three timber companies were 2.8:1; 3.1:1 and 1.9:1 while for community the ratios were 2.8:1; 2.4:1 and 2.8:1. The three-year average ratios were 3.2:1 for KFS, 3.0:1 for the timber companies and 2.7:1 for communities. This indicates that the equity ratios were very close meaning that all entities studied benefitted at the same level of respective inputs between 2012 and 2014. The conclusion is that PELIS implementation between 2012 and 2014 was equitable. It is also the view in this study that applying the Adams theory ratios can provide an opportunity to assess equity in PELIS under participatory forest management.

Key words: Plantation establishment, inputs, outputs, partners, communities, equity

Introduction

After the global discourse on the environment and development and the publication of the Bruntland report of 1987 'our common future', community participation in natural resource management was widely adopted as the most appropriate approach to address sustainable development and management of the resources including forests (Hobley and Shields, 2000; Alden and Mbaya, 2001; Willy, 2003; Schreckerberg *et al.,* 2006). The global re-emphasis of participatory approaches as necessary for sustainable development brought with it the question of equity (Nelson and Agrawal, 2006; Bram, 2011).

One of the community participation approaches is cultivation of forest lands known as Taungya or Shamba system, a concept that dates back to the early periods of plantation establishment in the 1800s. The approach, which was introduced in forest plantation establishment in 1886 in Myanmar spread to other Asian countries including India, Nepal and Vietnam (King, 1987; Jordan, *et al.*, 1992) and also in Africa during the colonial era (Enabor, *et al*., 1979, Ndomba *et al.,* 2015). The system continued to be applied in many countries as an innovative approach to establish forest plantations and facilitate participatory forest management (Nair, 1989; Thenya *et al*., 2007; Witcomb and Doward, 2009, Ndomba *et al.,* 2015). During the colonial rule, the practice was introduced in Africa to meet various needs among them, to provide wood fuel for steam locomotives, provide energy for mines and to meet other industrial demands for timber (FAO, 2000, Imo 2008). In post independence years, the system was adopted as a means of addressing landlessness, poverty and high costs in development of forest plantations. (Enabor *et al*., 1979; Chamshama *et al*., 1992; Kagombe, 1998; Imo, 2008).

Initially referred to as the Shamba system, it has evolved in Kenya from residential to non-residential farming and to total ban in the 1990s. It was reintroduced as plantation establishment and livelihood improvement scheme (PELIS), mostly facilitated by change in forest legislation in 2005 that incorporated participatory forest management (PFM) (GoK, 2005). However, the reintroduction of the system did not resolve the lingering question of equity. (Thenya *et al* 2007; Ongugo *et al*., 2008, Witcomb and Doward, 2009). This study seeks to analyze equity in PFM and apply the equity theory ratios as the basis for formulation of costs and benefit sharing mechanism in PELIS under PFM arrangements.

Materials and methods

Description of the study area*: Biophysical characteristics*

Gathiuru and Hombe forests are located at the South slopes of Mt Kenya about 290 Km from the capital city Nairobi and 45 Km from Nanyuki town. Gathiuru forest station is located at latitude -0.0500^0 and longitude 37.0833^0. The Gathiuru and Hombe forests are a part of Mt Kenya ecosystem in Central Kenya Highlands; one of the ten Country's management zones (Figure 1). Mt Kenya ecosystem has been under state management since 1943 (Logie and Dyson, 1962). The Ecosystem consists of three sub-ecosystems which include a national park occupying 71,510 ha, a natural forest reserve covering over 2,000 km^2 and gazzetted plantation forests measuring 8,994 ha. The plantations were mainly established between 2000 to 3000 metres above sea level (Emerton, 1999; KFS, 2010b; KWS, 2010).

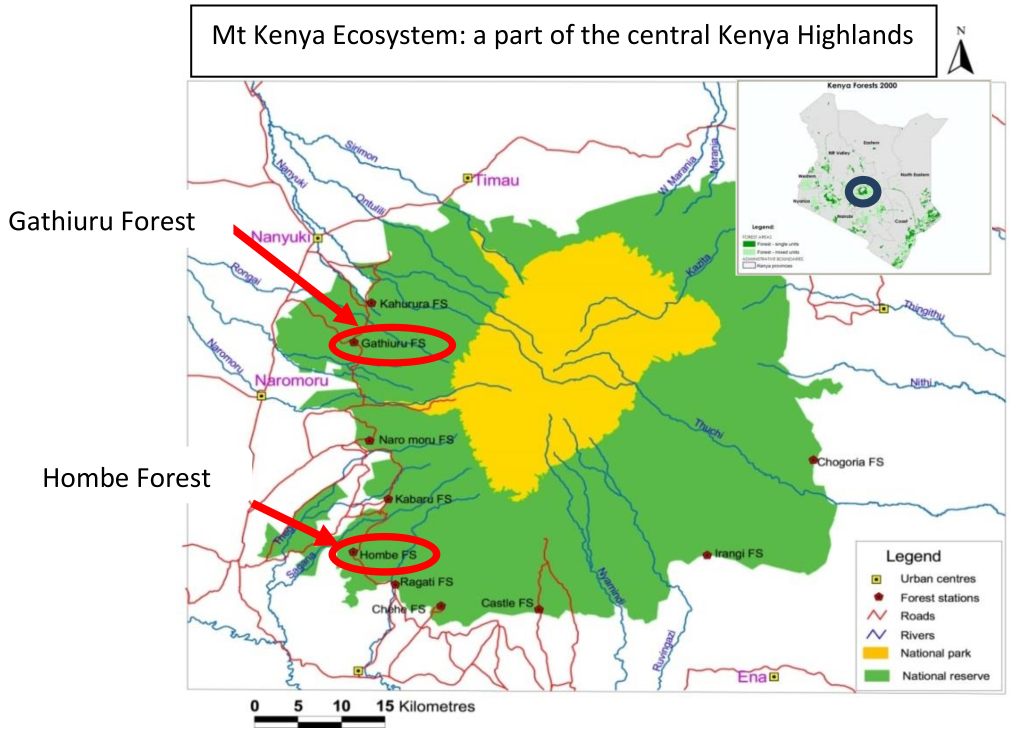

Figure 1. The location of Gathiuru and Hombe forests in the Mt Kenya ecosystem
Inset: The location of Mt Kenya Ecosystem on the Kenya forests map.
(Source Kenya Forest Service)

The vegetation in Gathiuru and Hombe forests include; forest plantations, indigenous forests, bush-land, grassland and bamboo. The natural forest covers 10,319.6 ha while plantations occupy 3,500 ha in both forests. Gathiuru forest holds 2,365 ha of plantations while about 1,150 ha are in Hombe forest. By 2013 a total of 969 ha in Gathiuru and 761 ha in Hombe were under PELIS. The main forest plantation species in the two forests are *Cupressuss lusitanica*, *Pinus patula*, *Pin*us *radiata* and *Eucalyptus glandis.* Small areas are also under planted indigenous tree species for example *Vitex kiniensis* (Gathiuru and Hombe plantation management plans 2012 to 2017 and 2010 to 2014 respectively).

Socio-economic characteristics

Gathiuru and Hombe forests are surrounded by agricultural communities of the Kikuyu and Meru origin who also keep cattle, goats and sheep (Nair, 1989; Kariuki, 2007). The farms around Hombe forest are of low productivity as a result of soil exhaustion from many years of cultivation. Land sizes have been subdivided to small scale areas of between 1 to 5 acres. Large areas outside the forest land have also been under tea and coffee farming especially around Hombe forest thereby increasing scarcity of land for food crop cultivation. Gathiuru forest is on the leeward side of Mt Kenya hence the surrounding land covered by mainly by bushy grasslands is drier and less productive. Livestock keeping is prevalent in the lower slopes (Emerton, 1999).

Study methodology

Sampling and data Collection: The study used a sample size of 321 respondents based on a confidence level of 95 % and a margin error of 5 % drawn from the whole of the PELIS population of 1947 persons working in both Gathiuru and Hombe out of which 225 (70 %) of the sample were drawn from Gathiuru forests and 96 (30 %) were drawn from farmers cultivating in Hombe forest. These percentages were based on the proportion of farmers in each of the forests with respect to the total. About 70 % (1338) of the total PELIS farmers worked in Gathiuru while 30 % (609) worked in Hombe forest (Table 1).

The number of individual respondents were picked based on the number of farmers allocated plots in each PELIS unit within each of the two forests. For example, if 30 % of the population was allocated plots in compartment A, a similar proportion of 30 % of the sample was drawn from the number of farmers allocated plots in that unit. The individual respondents were then systematically picked by selecting every sixth plot. Table 1 indicates distribution of the sampled respondents in all the PELIS units.

Table 1. The samples drawn from each PELIS unit

Name of Forest	Forest compartment	No of units in each block	No of farmers allocated plots in each unit.	Sample from each PELIS unit	% of sample
Gathiuru	Station	1	30	5	1.6 %
	Burgret	9	468	79	24.6 %
	Mugeria	8	840	141	43.9 %
	Gathiuru total	**18**	**1338**	**225**	**70.1 %**
Hombe	Polytechnique	1	48	6	1.9 %
	Gathunya	1	172	27	8.4 %
	Kiori	4	389	63	19.6 %
	Hombe Total	**6**	**609**	**96**	**29.9 %**

Primary data collection

Primary data was collected by use of a questionnaire which focused on household characteristics, socio economic status but more importantly on the total and average community inputs for the three-year period including labour, equipment and materials and time spent for meetings or other events under the PELIS. The seasonal outputs from agricultural crops cultivated by each individual and benefits from trees were considered. The total for communities and averages for individuals were applied to determine the Equity theory ratios.

Data analysis

The study applied descriptive statistical tools to determine characteristics of variables including frequencies and parameters measuring central tendencies-means and averages. Assessment of relationships between variable and comparison of inputs and outputs under PELIS was analyzed using cross-tabulation. The study analyzed inputs and outputs into the PELIS system by communities, the Kenya Forest Service and three key saw-milling companies that were engaged in timber business with KFS during the period under study . Secondary data provided by the Kenya Forests Service was used to analyze the inputs and outputs for the service and the saw-milling companies. The inputs and outputs were subjected to analysis based on Adams theory of equity.

Adams theory of equity postulates that the perception of equity in an employer / employee relationship is influenced by comparing inputs that each colleague contributes into the work and the outputs or gains each colleague gets as a result. The level of equity is then gauged based on comparison of ratios of outputs against inputs amongst the colleagues. The closer the ratios the more equitable is the relationship (Adams, 1963).

For example if person X compares with Person P:

Where the sum total of benefits for person X $= XB_{(i \ldots n)}$ and

the total inputs by person X $= XI_{(i..n)}$

The sum total of benefits for person P $= PB_{(i..n)}$ and

the total inputs by person P $= PI_{(i \ldots n)}$,

The Adams Equity ratios are achieved by $\frac{\text{Benefits (B)}}{\text{Inputs (I)}}$

By comparison,

Equity is achieved when: $$\frac{XB_{(i \ldots n)}}{XI_{(i \ldots n)}} = \frac{PB_{(i..n)}}{PI_{(i..n)}}$$

(Ratios can be real or perceived)

According to Equity theory situations are evaluated as just if ratios in the above formula are equal and unjust if unequal and when the ratio of one comparing with another is less or greater, inequity is perceived. In such circumstances, the comparing person reacts in an attempt to restore the inequity (Adams, 1963, Walster *et al.*, 1973). This paper takes the PELIS implementing communities, the Kenya Forest Service and the Saw-milling companies as partners who contribute to and benefit from the forest plantation resource. The theory of equity is applied to assess the proportions of outputs against inputs among the three partners.

Parameters considered in analysis of equity in costs and benefits under PELIS.

In the proposed model, the total community labour inputs for example in seedlings production took into account the sum of individual inputs both in cash and in kind (SP_i) where subscript 'i' represents all of the individuals inputs in that particular task. The total costs or inputs SP for a CFA with 'n' number of members becomes $Sp_{(i \dots n)}$.

It therefore follows that the total input by a given CFA in tree seedlings production will be

$SP = Sp_{(i..n)}$, Where $Sp_{(i..n)} = \sum(Sp_1 + Sp_2 \dots Sp_n)$

A similar process was carried out for all tasks and inputs by individuals involved in any given activity. The total inputs become the value of the sum of all activities by all individuals which yields the proportion of benefits received by community and individuals.

The total benefits from the model computed included all monetary and material products from the forests including both tree and agricultural production:

Total Benefits = ∑(TPs(i…n)+ Prs(i…n)+ Ths (i…n)+ Hvs(i …n) +Grs(i..n) + others….) where

TPs(i…n) = All benefits derived from Timber products
Prs(i…n) = all benefits derived from prunnings
Ths (i…n) = All benefits derived from Thinnings
Fw(i …n) = All benefits derived from firewood
Grs(i..n) = All benefits from grazing
OB(i..n) ….= Any others measurable benefits…

Parameters applied in determining Equity Inputs and Outputs are as shown in Annex 1

Results

In the study area, the main forest plantation tree species planted are Cypress and Eucalyptus while potatoes and legumes (peas and beans) are the main agricultural crops cultivated. Up-to 84.8 % of the sampled respondents planted Cypress and 10.7 % planted Eucalyptus during the three-year period of the study. About 4.5 % of the respondents planted other species including *Pinus radiata, Pinus patula* and *Vitex kiniensis.* The results in the study indicated that between 87.8 % and 95.2 % of the respondents farming in Gathiuru forest cultivated potatoes while in Hombe forest the percentage was between 92.2 % and 94.1 %. Legumes (beans and peas), maize and vegetables are produced at minimal levels in the two forest areas. Further analysis shows that 90 to 93 % of the respondents produced potatoes as a cash crop and 60 to 76 % of those who cultivated legumes (beans and peas) produced the crops for subsistence purpose (Table 2).

Table 2. Farmers cultivating cash crops and subsistence crops in Gathiuru and Hombe Forests

Percentage of farmers producing Cash crops			
Year	**Potatoes**	**Legumes (beans & peas)**	**No crops reported**
2012	90.0 %	0.7 %	9.3 %
2013	92.1 %	1.0 %	6.9 %
2014	93.1 %	1.7 %	5.2 %
Farmers cultivating subsistence crops			
Year	**Potatoes**	**Legumes (beans & peas)**	**No crops reported**
2012	1.0 %	68.0 %	30.9 %
2013	0.7 %	62.2 %	37.1 %
2014	1.7 %	76.6 %	21.6 %

Input /Output Analysis for PELIS Communities in Hombe and Gathiuru

Inputs: On average the PELIS Gathiuru farmers cultivated 128 ha per year while the average for Hombe farmers was 100 ha per year (Table 3 and 4). The average inputs for production of both agricultural and tree crops for farmers in Gathiuru forest was Ksh 68,185 per hectare and that for Hombe PELIS farmers was Ksh 83,020 per hectare (Table 3). The farmers in Hombe forest spent more investments in the program compared to those farming in Gathiuru forest.

Table 3. Total quantifiable inputs for PELIS communities per hectare.

Community inputs: total production per hectare. (Standardized per ha)					
	Year of Inputs	Area cultivated each year (In hectares)	In puts in agricultural cash & subsistence crops production /ha	In puts into plantation (tree crop) production per ha	Overall inputs (agric & trees) production per ha
Gathiuru Forest	2012	113	46,276	15,888	62,164
	2013	128	46,518	18,647	65,165
	2014	142	61,690	15,536	77,226
	Average per hectare	**128**	**51,494**	**16,690**	**68,185**
Hombe Forest	2012	99	62,127	29,896	92,022
	2013	102	50,927	20,752	71,679
	2014	99	65,035	20,324	

				85,359
Average per hectare	**100**	**59,363**	**23,657**	**83,020**

Outputs*:* Farmers in Gathiuru earned an average of Ksh 209,116 per hectare while in Hombe the average earnings were KES 192,633 per hectare.

Table 4. Total quantifiable outputs for PELIS communities per hectare.

		Communities standardized earnings: outputs per hectare.				
	Year of outputs / Earnings	Area cultivated each year (In hectares)	Earnings Potatoes + legumes per ha	Earnings from assorted timber products per ha	Firewood & domestic use benefits per ha	Aggregate earnings per hectare
Gathiuru Forest	2012	113	274,038	1,168	4,128	279,335
	2013	128	194,357	867	5,002	200,226
	2014	142	147,015	0	773	147,789
Average per year		128	205,137	678	3,301	209,116
Hombe Forest	2012	99	98,140	0	1,441	99,582
	2013	102	110,088	0	1,486	111,575
	2014	99	361,176	1,010	4,556	366,742
Average per year		100	189,802	337	2,495	192,633

Inputs and outputs analysis for KFS

Inputs: The total cost that KFS incurs in establishing one hectare of cypress plantation is Ksh 271, 966. (Table 5). These calculations are based on annual task rates which are stipulated in the Kenya Forest Service Technical Orders and also used to develop the KFS 2012 to 2017 Plantation Enterprise Business Plan. The daily wage rate remained Ksh 421 during the period of the study.

Table 5. Cost for establishing a typical one-hectare cypress stand

Typical silviculture commitments for a well-managed cypress stand				
	Year	Person days	Daily wage	Cost (Ksh/Ha)
Seedlings	1	110	421	46,310
Clearing	1	25	421	10,525
Staking	1	11	421	4,631
Planting	1	25	421	10,525
Weeding	1	30	421	12,630
Weeding	2	28	421	11,788
Weeding	3	24	421	10,104
Pruning	3	4	421	1,684
Pruning	4	12	421	5,052
Pruning	7	15	421	6,315
Pruning	11	11	421	4,631
Pruning	15	20	421	8,420
Thinning	4	23	421	9,683
Thinning	8	13	421	5,473
Thinning	15	9	421	3,789
Inventory & mapping	15	12	421	5,052
Inventory & mapping	25	8	421	3,368
Protection (one beat = 30 ha)	28	270	421	106,092
Fire breaks (Maintenance)	10	6	421	2,526
Fire breaks (Maintenance)	15	4	421	1,684
Fire breaks (Maintenance)	25	4	421	1,684
Total				**271,966**

Source: Kenya Forest Service business plan and business model 2012-2017 and KFSTOs (KFS10c, 2013a and b)

Outputs: KFS plantation sales and revenues**:** To determine the outputs for the Kenya Forest Service (KFS) and inputs for saw-milling companies, sales and trading data for three timber trading companies were used. The companies include Timsales, Rai-ply and Comply Ltd companies. Analysis of the secondary data included areas in hectares harvested annually by each company, the timber volumes derived from harvests and amounts paid each year for the timber volume determined from the standing trees. Based on the KFS sale and revenue reports of 2011/2012 to 2015/2016, it was established that in 2012, KFS received an average of Ksh

1,135,333 per hectare from Timsales company which clear felled 105 ha and obtained 421 $m^3$of round wood per hectare. In 2013 the KFS got on average Ksh 789,709 while in 2014 the revenue collected was an average of Ksh 614,136 per ha. Rai-ply and Comply companies paid revenue of Ksh 1,158,189 and Ksh 997,625 per ha respectively in 2012. In 2014 KFS received Ksh 817,782 per ha from Rai-ply Company (Table 6).

Table 6. KFS outputs-based on revenues from Timsales, Rai-Ply and Comply timber companies.

KFS income based on three key trading companies				
Company harvesting timber	Yr timber was harvested	**KFS revenues from the sawmilling companies**		
		Area harvested	Total revenue Collected	Average revenue per ha
Timsales	2012	105	119,210,000	1,135,333
	2013	348	274,897,757	789,709
	2014	357	219,492,264	614,136
	Average in the year	270	204,533,340	757,531
Rai-ply Timber Company	2012	127	147,090,000	1,158,189
	2013	628	341,727,232	544,585
	2014	146	119,559,724	817,782
	Average in the year	300	202,792,319	675,224
Comply Timber Company	2012	299	298,290,000	997,625
	2013	504	400,573,111	795,577
	2014	249	268,317,978	1,079,750
	Average in the year	351	322,393,696	919,374

Input / Output analysis for the three saw-milling companies

Inputs: The payments the companies made to KFS are considered as output or earnings to KFS while for the companies, these payments are viewed as the inputs into the investments. Results indicate that the Companies' inputs ranged from Ksh 400,000 to about Ksh 1.2 million per ha. Timsales company invested over Ksh 1,135,333 per hectare in 2012 and Ksh 614,136 per ha in 2014. Rai-ply invested Ksh 1,158,189 in 2012. Comply Co Ltd input were about Ksh 1 million per hectare in 2014 (Table 7). On average Timsales' average inputs for the three years were Ksh 757,531 per ha, Raiply's average inputs were Ksh 675,224 while Comply Ltd inputs were Ksh 919, 374 per ha for the same period.

Table 7. Inputs into PELIS process by saw milling companies.

Inputs into PELIS system by the selected saw-milling companies {The revenue paid to KFS becomes the Saw-milling companies' inputs (Ksh/Ha)}					
		Amounts companies paid to KFS during the year			
Company harvesting timber	**Yr timber was harvested**	**Area harvested**	**Average Vol m^3/Ha**	**Total amounts paid to KFS**	**Company inputs expressed in (Ksh/Ha)**
	2012	105	421	119,210,000	1,135,333
Timsales	2013	348	308	274,897,757	789,709
	2014	357	214	219,492,264	614,136
Average per year		270	315	204,533,340	757,531
	2012	127	471	147,090,000	1,158,189
Rai-ply	2013	628	176	341,727,232	444,585
	2014	146	264	119,559,724	817,782
Average per year		300	304	202,792.319	675,224
	2012	299	307	298,290,000	997,625
Comply	2013	504	274	400,573,111	795,577
	2014	249	317	268,317,978	1,079,750
Average per year		351	299	322,393,696	919,374

Outputs: The net benefits from the volume of timber purchased by the companies are calculated based on a timber recovery rate of 62.2 % determined by the Kenya Forest Service for Nyeri County timber industries. Kenya Forest Service undertakes a market survey for timber prices and determines rates to apply in setting timber prices prescribed in the Kenya Forest Service Technical Orders (KFSTOs). The market rates per m^3 of wood determined annually were used to estimate volume based sales for each sawmilling companies each year. The total earnings are also calculated less 50 % which is assumed to go into the companies' operational costs. Gains made from value addition processes are not considered in the analysis.

Assuming the 50 % operational costs, the results indicated that in the year 2014, Timsales Co. Ltd earned about Ksh 2.644 million per ha, Rai-ply earned Ksh 2.350 million and Comply Co Ltd earned approximately Ksh 2.817 million per ha (Table 8).

Table 8. Sawmill outputs from plantation forests.

Determining sawmilling company sales each year Net outputs at 62.2 % recovery and assumed 50 % operational costs for the selected saw-milling companies.								
Company name & year of business transaction				Average Vol m^3/Ha	Annual rates based on market prices Ksh /m^3	Ksh/ha= Avg Vol m^3/ha X sale rates per m^3	Taking 62 % timber recovery rate:	Assume 50 % of sales is operational cost
Company Name	Year timber was sold	Total Volume harvested in (m^3)	Area harvested (Ha)	Average Vol m^3/Ha = Total Vol (M^3) /Total area (ha)	Market rates used by KFS	expected sale of total volume of timber sold would be (Ksh/ha)	Outputs= (62 % x expected total sales) Ksh per ha	Net output becomes (50 %*62 %X Outputs) per ha
Timsales	2012	44,248	105	421	25,300	10,661,661	6,610,230	3,305,115
	2013	107,383	348	308	28,500	8,791,788	5,450,909	2,725,454
	2014	76,451	357	214	28,700	6,139,206	3,806,308	1,903,154
	Average per year	76,027	270	315	27,500	8,530,885	5,289,149	2,644,574
Rai-ply	2012	59,874	127	471	25,300	11,927,655	7,395,146	3,697,573
	2013	110,551	628	176	28,500	5,021,023	3,113,034	1,556,517
	2014	38,621	264	264	28,700	7,581,476	4,700,515	2,350,258
	Average per year	69,682	300	304	27,500	8,176,718	5,069,565	2,534,783

Comply	2012	91,659	299	307	25,300	7,755,762	4,808,572	2,404,286
	2013	137,953	504	274	28,500	7,808,683	4,841,383	2,420,692
	2014	78,697	249	317	28,700	9,088,961	5,635,156	2,817,578
	Average per year	102,770	351	299	27,500	8,217,802	5,095,037	2,547,519

Comparing equity theory ratios:
The **Equity theory ratios = Outputs/Inputs,** computed based on Adams theory**.** In the study, the output and inputs are determined using the hectare as the common unit of measure.

Results show that Kenya Forest Service ratios varied from the lowest ratio of 2.0:1 in 2013 where Rai-ply paid the lowest revenue of Ksh 544,545 per ha. The highest ratio was 4.3:1 in 2013 again where Rai-ply paid the highest revenue of Ksh 1,158,189 per ha. Considering revenues paid by Comply, the lowest ratio was 2.9:1 and the highest 4.0:1 (Table 9).

With regard to the three company output: input ratios the lowest was 2.4:1 for Comply company in 2012 and the highest ratios were 3.9:1 in 2013 where Rai-ply paid the lowest revenues 44,545 (Table 9)

Table 9. KFS outputs: inputs ratios

KFS outputs : inputs ratios based revenues and production per ha for three sawmilling companies

	Timsales Timber Company				**Rai-ply Timber Company**				**Comply Timber Company**			
	2012	2013	2014	Average	2012	2013	2014	Average	2012	2013	2014	Average
Revenue (output) Ksh/ ha	1,135,333	789,709	614,136	846,393	1,158,189	544,585	817,782	840,185	997,625	795,577	1,079,750	957,651
Inputs Ksh/ ha	271,966	271,966	271,966	271,966	271,966	271,966	271,966	271,966	271,966	271,966	271,966	271,966
(outputs: inputs) ratios	4.2:1	2.9:1	2.3:1	3.1:1	4.3:1	2.0:1	3.0:1	3.1:1	3.7:1	2.9:1	4.0:1	3.5:1

Saw milling company outputs : inputs ratios based on production per ha

	Timsales Timber Company				**Rai-ply Timber Company**				**Comply Timber Company**			
output Ksh / ha	3,305,115	2,725,454	1,903,154	2,644,574	3,697,573	1,556,517	2,350,258	2,534,783	2,404,286	2,420,692	2,817,578	2,547,519
inputs Ksh/Ha	1,135,333	789,709	614,136	846,393	1,158,189	544,585	817,782	840,185	997,625	795,577	1,079,750	957,651
(outputs: inputs) ratios	2.9:1	3.5:1	3.1:1	3.1:1	3.2:1	2.9:1	2.9:1	3.0:1	2.4:1	3.0:1	2.6:1	2.7:1

When all community gains from agricultural and tree crops were compared against all community inputs into PELIS, the lowest equity theory ratio of output against inputs was 1.1:1 in 2012 for farmers in Hombe forest and the highest was 4.5:1 in 2012 Gathiuru forest. The lowest ratio in Gathiuru forest was 1.9:1 while for Hombe farmers, the lowest ratio was 1.1:1 in 2012 while the highest was 4.3:1 in 2014. The average for the three years was 3.1:1 in Gathiuru and 2.3:1 for farmers in Hombe.

Table 11. Communities' Outputs: Inputs ratios

Community ratios: (Outputs: Inputs) based on per hectare production

Outputs vs inputs	**Gathiuru**				**Hombe**			
	2012	2013	2014	Average	2012	2013	2014	Average
Aggregate earnings per hectare	279,335	200,226	147,789	209,116	99,582	111,575	366,742	192,633
(Agric & tree inputs) production per ha	62,164	65,165	77,226	68,184	92,022	71,679	85,359	83,020
Ratios (Outputs: inputs)	4.5:1	3.1:1	1.9:1	3.1:1	1.1:1	1.6:1	4.3:1	2.3:1

The highest average ratio for KFS was in 2012 where it was 4.1:1. The highest average ratio for the three companies was in 2013 where it was 3.1:1 but communities had the least average in the same year-2.4:1 For communities farming in the two forests, the average ratio was 2.8:1 for the period of the three years while for KFS it was 3.4:1 and for the three companies it was 3.0:1 for the same period (Table 12). The range of ratios is between 2.6:1 and 4.1:1 for the Kenya Forest Service while for the three companies the ratio ranges between 1.9:1 and 3.1:1. For the communities farming in Gathiuru and Hombe forests, the ratios range from 2.4:1 and 3.1:1

Table 12. Equity theory ratios for KFS, Saw-milling companies and PELIS communities

PELIS Partner	**Company**	**2012**	**2013**	**2014**	**Average**
Kenya Forest Service (outputs: inputs) in PELIS	Timsales	4.2:1	2.9:1	2.3:1	3.1:1
	Rai-ply	4.3:1	2.0:1	3.0:1	3.1:1
	Comply	3.7:1	2.9:1	4.0:1	3.5:1
Average		4.1:1	2.6:1	3.1:1	3.2:1
Sawmilling Companies (Outputs: inputs) in PELIS	Timsales	2.9:1	3.5:1	3.1:1	3.2:1
	Rai-ply	3.2:1	2.9:1	2 .9:1	3.0:1
	Comply	2.4:1	3.0:1	2.6:1	2.7:1
Average		2.8:1	3.1:1	1.9:1	3.0:1
PELIS Communities (Outputs: inputs) in PELIS	Gathiuru	4.5:1	3.1:1	1.9:1	3.2:1
	Hombe	1.1:1	1.6:1	4.3:1	2.3:1
Average		2.8:1	2.4:1	3.1:1	2.8:1

Parameters to consider for improved equity in costs and benefits

To ensure equity the study proposes enhancement of accountability and transparency when formulating regulations and guidelines for cost –benefit sharing mechanisms. The study revealed that some of the key parameters that influence inputs and outputs in PELIS include participation in silvicultural operations which according to communities view are technical and tedious. These activities include staking, pitting, seedlings production, planting, pruning and thinning. The communities argue that they should only be engaged in land preparation and weeding which has direct effect on agricultural production. In determining community inputs, the individual input into each specific task should be taken into account.

Discussion

Despite some authors highlighting the value and benefits of shamba system to communities and governments (Chamshama *et al.*, 1992; Adenkule and Bakare 2004; Thenya *et al*., 2007; Kalame *et al.*, 2011; Khalumba *et al*., 2015), the approach has been blamed in equal measure for contributing to forest destruction including in the Mt Kenya Ecosystem. (Jordan *et al.*, 1992; Bussmann, 1996; Gathaara, 1999; Kariuki, 2007; Maathai, 2009; Witcomb and Doward 2009). This is not because the system is destructive but rather the system has been subjected to abuse by officials and persons taking advantage of legislative gaps and weaknesses in its implementation and governance (Kagombe and Gitonga, 2005; Musyoka, 2008).

Under the Plantation Establishment and Livelihood Improvement Scheme, the farmers are expected to benefit from availability of land for farming, the agricultural produce and other ecological services that forests may provide. Under these arrangements, the forest managers gain from reduction in the cost of forest plantation development and the revenues from the sale of the tree products. The farmers' gains are limited to food production, income generation through sale of the agricultural crops (Witcomb and Doward 2009; Ndomba *et al.,* 2015). According to communities' perception inequity exists in costs and benefit sharing in this participatory agreement. While the communities undertake activities such as seedlings production, pitting, staking, tree planting, pruning, thinning, policing and coppice reduction and other activities all geared towards establishment of the forest plantations the communities view these as technical obligations of the forestry agencies and are seen to be over bearing on the farmers. In contrast the forest agencies play no role in support of production of the agricultural crops from which communities benefit. Some communities argue that the forestry agency should separately compensate for example in partial or complete wages for the communities' inputs towards the plantation development activities. This study from a social perspective supports the communities 'position that being a symbiotic relationship; participatory interactions are enhanced when partners support each other for mutual benefits. Similar views are held by Chamshama *et al.,* 1992 that "application of the system is beneficial in tree survival, food crop production, financial income to the peasant farmers and reduction of forest plantation establishment costs and therefore the practice should be sustained."

However, casting the community as 'peasant farmers' 'forest users' and the shamba system as a forest –user right tends to demean and weaken the power devolvement to communities thus limiting the programmes potential to both facilitate and embody the participation of local people in forest management (Witcomb, and Doward, 2009). It also fails to capture emerging socio economic dynamics where farmers are gradually empowered improved status. Ndomba *et al*., 2015, found that peasant farmers in Mt Meru forest apply expensive agrochemicals and attributed this to increased economic capacities of farmers.

Farmers have reported improved livelihoods for example (Mbuvi, *et al.,* 2009) relating to communities involved with coastal forests and (Matiku, 2013; Mutune, 2016) for communities neighboring the Mau Forest Complex. In this study 98.9 % of farmers in Gathiuru forest and 85.3 % of those in Hombe forest view PELIS as a profitable engagement. Regardless of this sense of profitability, the perception of inequity persists. The study found out that the communities attribute the income from agricultural crop to their hard work and intense inputs into crop production and could not relate the benefits to trees or the forest. The inability to attribute benefits to trees may have a negative impact and at times is blamed for the destruction of trees often experienced in past application of the system. The farmers argue that they further pay a fee of Ksh 500 on average for each plot of land allocated and also for membership to the

CFAs. The views in the study is that Adam's equity theory ratios can address the perception of inequity .

Findings in this study indicate that the ratios of outputs: inputs for KFS and those of sawmilling companies were very close (3.2:1 and 3.0:1) respectively during the three years of study. The average ratios for the communities were slightly less 2.8:1. This result indicates that there was equity between the KFS and the saw millers but even though the ratio for communities was slightly less, there was no significant difference between all the ratios. However, it would be motivating to protect the tree seedlings if benefits associated with tree would be allowed to trickle to farmers. While this would enhance the equity ratios, it is also likely to enhance the communities' sense of tree ownership and hence motivate farmers to protect the trees.

The Shamba system has often been hailed as one of the successful agroforestry systems that has supported expansion of the forest cover, helps meet domestic and industrial demand for wood and supports rural livelihoods (Nair, 1989). Researchers have pointed out that if well managed the shamba system is a suitable approach that can ensure sustainability of forests (Kagombe and Gitonga, (2005) points to the system's capacity to provide multiple benefits both to government and communities and the need for good governance, Agyeman *et al.*, (2003) refers to need for modified taungya systems to address emerging community needs and acceptable benefit sharing while Witcomb and Dorward, 2009 addressed need for administrative transparency and clear benefit sharing mechanisms.

While the general view has been that communities are not adequately compensated for the inputs into the participatory plantation establishment, results of this study reveals the output: input ratios for KFS and saw-milling companies are relatively close but the communities' ratio, were slightly lower comparatively. This reflects the discontent often expressed by communities but also supports the KFS arguments against sale of forest plantation based on reserve prices but rather sale based on a free market and open bidding as the options to raise the value of the plantations and subsequent revenues (KFS 2013a). According to Adam's theory of equity, the parties that perceive inequity in the relationship seek alternatives that attempt to address the inequity. The reaction of communities in participatory forest management is often to contend with Kenya Forest Service to provide the communities with sawmilling opportunities. However, limitations in terms of government procurement requirements and financial resources make this alternative difficult leaving the communities contesting against plantation allocations to saw-milling companies.

The perception of communities, other stakeholders and some researchers that the benefits derived from PFM are insufficient may negatively affect the communities' morale in the long term leading to inefficiencies in the implementation of the PFM approach. There is need to explore the scope of costs and benefits sharing mechanisms in order to develop appropriate policies that would provide sufficient incentives for communities to effectively and sustainably participate in forest management (Jordan *et al.,* 1992; Matiku *et al.,* 2011). The study proposes that applying the equity theory ratios can provide an opportunity to address inequity in participatory forest management. Aggregating all inputs specific to each partners' inputs and comparing the outputs amongst the concerned partners is an important part of this process.

Conclusion

Applying the equity theory ratios provides an opportunity to assess inequity in PELIS under participatory forest management and gives an indication of possible areas of intervention.

A formula which integrates all inputs from partners and compares each output as a benefit to each partner is an appropriate basis to assess Equity. The study concludes that the output/input ratios for KFS, the timber companies and the communities were very close between 2012 and 2014 even though the community ratios were slightly lower. According to Adam's theory, it means that the participants of PELIS benefitted at the same level with respect to their inputs between 2012 and 2014. Community outputs could be enhanced by supporting communities in production and marketing of the agricultural crops thereby decreasing further the Equity ratio gap. A similar effect could also be achieved if the saw-milling companies and the forestry agencies re-distributed part of their benefits to the communities' under the umbrella of Corporate Social Responsibilities (CSR). This would also contribute in further bridging the gap between the ratios, improve equity, and enhance relationships among players and impact sustainable forest management positively.

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Annex 1. Spectrum of plantation establishment costs and proposed distribution of subsequent benefits/profits

Cost Activities	**Land preparation Digging, Harrowing, staking, pitting**	**Seedlings production**	**Planting: (Setting and covering)**	**Weeding**	**Pruning**	**Thinning**	**Harvesting**	**Post harvesting costs**
Sum of total activity Costs	LP= $Lp_{(i\ldots n)}$	SP= $Sp_{(1\ldots n)}$	PC= $Pc_{(i\ldots n)}$	WC= $Wc_{(1\ldots n)}$	PR= $Pr_{(1\ldots n)}$	TH= $Th_{(1\ldots n)}$	HV= $Hv_{(1\ldots n)}$	PH= $Ph_{(1\ldots n)}$
Individual sub-activity costs	$Lp_{(i\ldots n)}= \sum Lp_1+Lp_2\ Lp_3 \ldots Lp_n)$	$Sp_{(1\ldots n)}= \sum Sp_1+Sp_2 \ldots Sp_n)$	$Pc_{(i\ldots n)}= \sum ((Pl_1+Pl_2 \ldots Pl_n)$	$Wc_{(1\ldots n)}= \sum Wd_1+Wd_2+Wd_3)$	$Pr_{(1\ldots n)}= \sum Pr_1+Pr_2+P_3)$	$Th_{(1\ldots n)}= \sum Th_1+Th_2+Th_3)$	$Hv_{(1\ldots n)}= \sum Hv_1+Hv_2 \ldots v_n)$	$Ph_{(1\ldots n)}= \sum Ph_1+Ph_2 \ldots Ph_n)$
Other parameters	Other costs (OCs) = (meetings, workshops , conflict resolutions) $OC_{(i\ldots n)}= \sum OC_1+OC_2 + OC_3 \ldots OC_n)$				Other benefits $(OB_{(i..n)})$=			
Monetary Benefits	Total inputs =(LP:SP:PC:WC:PR:TH:HV:PH+ OCs) (OC-Other costs) Total Benefits= $\sum(TPs_{(i\ldots n)}+ Prs_{(i\ldots n)}+ Ths_{(i\ldots n)}+ Fw_{(i\ldots n)} + Grs_{(i..n)} + OB_{(i..n)} \ldots)$ (OB- Other Benefits) The costs and benefits for agricultural productions should also be included. Sharing of costs and benefits can then be based on the outcome of the computations. Discounting may be essential.							

Soil Carbon Sequestration Differentials among Key Forest Plantations Species in Kenya: Promising Opportunities for Sustainable Development Mechanism

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Abstract
This study addressed soil carbon sequestration differentials among key forest plantation species commonly grown in Kenya and their implication on climate change mitigation in the context of clean/sustainable development mechanism. Soil samples were collected at 0 to 20, 20 to 50 and 50 o 80 cm depth using soil augur from various sub-plots of *Pinus patula, Cupressus lusitanica*, *Juniperus procera* and *Eucalyptus saligna/grandis* in Central Kenya. A composite sample of about one kilogram from each depth was packed into polythene bags for analysis of carbon, soil pH, nitrogen, phosphorous and potassium. Litter fall of about 300 to 500 grams collected from sub-plots was packed into polythene bags for analysis of N and C. *Pinus patula* had significantly ($p<0.01$) higher amount of soil carbon (132.2 ± 12.55 MgC ha-1) compared with *Cupressus lusitanica* (114.4 ± 12.55 MgC ha-1) and *Eucalyptus saligna* (85.0 ± 12.55 MgC ha-1). There were also significant differences ($p<0.01$) on soil carbon among species within and between sites. The amount of soil carbon sequestered by *P. patula* was almost twice above and below-ground carbon whereas that of *C. lusitanica* and *E. saligna/grandis* were about 1.2 and 1.3 times higher, respectively. These differentials on carbon sequestration underscore an important consideration especially in the development and implementation of afforestation and reforestation activities under Clean/Sustainable Development Mechanism (SDM). In this regard, the total valuation of carbon sequestered by different species need to be considered if the returns especially on certified and voluntary emission reduction investments in AR CDM and SDM would be realized.

Key words: soil carbon, tree species, sustainable development mechanism and sites

Introduction
Soil organic carbon (SOC) is among of the five carbon pools that are reported under United Nations Framework Convention on Climate Change (UNFCCC). However, the estimation of these carbon pools, namely; above-ground biomass, below-ground biomass, litter, deadwood and soil organic carbon, has largely concentrated on above and below-ground biomass in different forest types. This has continued to undermine the total value of other carbon pools that have

significant potential in climate change mitigation. For example, studies carried out on estimation of SOC have shown that forest soils consists about 73 per cent of global soil carbon storage, which is the largest active terrestrial carbon reservoir for both a sink and atmospheric carbon. Specifically, estimation of SOC in temperate forest ecosystems have shown that carbon pool in forest soil is almost as twice as large as the pool in the forest vegetation (Liu *et al*., 2016; Kumar and Sharma, 2016). This demonstrates the significance of SOC in the forest ecosystem that remains instrumental not only as a carbon sink but also on determining the productivity of the forest and tree resources. Forests with high levels of SOC directly influence the above and belowground biomass. Equally, exposed soils due to land degradation, deforestation and other poor land management practices results to emission of carbon back to the atmosphere resulting to global warming. For example studies conducted by Djukic *et al*. (2018) revealed that litter decomposition as influenced by various climatic factors such as temperature, moisture and other non-climatic factors have resulted to enormous amount of carbon emitted to the atmosphere. This underscores the need for investing both financial and human resources to estimate and report on SOC from different forest types globally. It also signals for the need to monitor shifts on land uses in the context of Agriculture, Forestry and Other Land Use (AFOLU) as well as Land Use, Land-use change and Forestry (LULUCF).

The global shifts on AFOLU and LULUCF provides valuable information on SOC lost and gained depending on the land use patterns that are essential, especially when reporting on agriculture and forest based Nationally Determined Contributions (NDCs). It's estimated that about 20 % of the global anthropogenic carbon dioxide is associated with land use changes, either from forestry to agriculture, deforestation, human settlement, infrastructure, and food-fibre-fuel nexus among other determinants including extractive industries. In this regard, countries have embarked on national inventories to estimate the forest and tree resources in order to determine the coverage as well as approximating value of forests in provisioning of good and services at national, regional and international levels in the face of climate change. The global statistics shows that Africa's total forest cover is about 624 million ha of which 16 million ha are forest plantations established for production of industrial round wood, afforestation of degraded land, protection of environment among others (FAO, 2015; Keenan *et al.*, 2015). These forest statistics shows that African forests have a significant potential in carbon sinks thus playing a vital role in the overall carbon cycle (Henry *et al*., 2009).

However, Africa has not invested much on understanding the carbon dynamics in the forest sector, especially considering the SOC among the total carbon pools. This is an important aspect because a number of African countries are implementing afforestation and reforestation programmes to enhance their forest cover that is below the FAO recommendations of at least 10 % forest cover. The efforts to improve forest and tree cover has attracted various incentive programmes at national, regional and international levels. For example, UNFCCC through ratification of Kyoto Protocol (KP) that is coming to an end in 2020, embraced afforestation and reforestation (AR) in the Clean Development Mechanism that is expected to be replaced by Sustainable Development Mechanism (SDM) by 2021. Under the CDM, there exist compliance carbon offset markets for trading certified emission reductions (CERs) from AR programmes among other sector based activities. The available data shows that African countries that ratified the Kyoto Protocol have made very little progress in developing forest based carbon projects to tap these global opportunities in the investment of forest sector. The countries that have embraced AR-CDM have majorly dealt with above and below-ground carbon pools with little emphasis on SOC, deadwood and litter. This demands step wise approaches in estimating SOC in different forest types in order to optimize on the carbon offset returns and provide the total value of forest in the regulation of climate change. The introduction of Reducing Emissions from Deforestation and forest Degradation (REDD+) and voluntary carbon offset markets has also provided impetus to the African governments in implementing AR programmes.

Kenya that is known to be low forest and tree cover country is currently thriving to achieve 10 % forest cover by 2030 through different strategic interventions. The country has piloted five AR-CDM activities in government forests, namely; Mau Forest Complex, Mt Kenya and Aberdare Range. The country has also piloted seven forestry sector voluntary projects including Rukinga REDD+ phase I and II, which is the first world project to have issued verified carbon unit certificates. These efforts are expected to enhance carbon stock and improve forest cover. In spite of these notable progress that has profiled Kenya as the most successful African country in tapping the forestry segment of the global certified and voluntary carbon offset markets, none of the AR-CDM activities addresses the soil carbon estimation. There are various reasons advanced based on the literature for neglecting soil organic carbon based on the type of soils and other considerations. This has continued to indicate less interest on SOC that might result to the overlooking of the available potential of SOC in different forest types and tree species that are currently used in AR activities. This study therefore sought to determine soil carbon sequestration differentials among selected key species in forest plantations in Kenya and their future implications on sustainable development mechanism.

Materials and methods

Description of study sites

This study was carried at Kiambu and Nyeri Counties in the Central Highland Conservancy. Kiambu County covers an area of 1,323.9 Km² lies between latitudes 0°75′ and 1° 20′ south of Equator and longitudes 36° 54′ and 36° 85′ east. Its agro-ecological zone (AEZs) extend in a typical pattern along the eastern slopes of the Nyandarua (Aberdare) Range. It has great potential for tea growing in Githunguri and Limuru, coffee, dairy farming and pyrethrum, among others. It is the most densely populated area with a density of 562 persons per km^2 compared to 280 persons per km^2 in 1979, with a population growth rate of 8.4 % (Kenya National Bureau of Statistics [KNBS], 2010; Jaetzold *et al*., 2006; Republic of Kenya, 2005a).

Nyeri County forms part of Kenya's eastern highlands. It is the most expansive covering an area of 3,266 km^2 and is situated between Longitudes 36º and 38º east and between the equator and Latitude 0º 38´ south. The population densities at Nyeri North and Nyeri South were 142 and 351 persons per km^2, respectively (Kenya National Bureau of Statistics [KNBS], 2010; Republic of Kenya, 2005b). The main physical features of Nyeri County are Mt. Kenya (5199 m.a.s.l.) to the east and the Aberdare range (3999 m.a.s.l.) to the west. These mountains are of volcanic origin. They determine relief, climate and soils, and consequently, the agricultural potential of the County (Republic of Kenya, 2005b). The average annual rainfall ranges from 2200 mm on the most easterly exposed edge of the Aberdare range to 700 mm on the Laikipia Plateau. The economic livelihood of people in this County is dependent on agriculture as over 67% of the total area is arable land with main agro-ecological zones (AEZ) UM 2 (main coffee zone 2), LH 4 (Cattle-sheep-Barley Zone) and LH 5 (Ranching zone) (Jaetzold *et al*., 2006).

Study design

A list of all forest stations managed by Kenya Forest Service in Kiambu, Kirinyaga, Murang'a, Nyandarua and Nyeri Counties in Central highland Conservancy was obtained. Kiambu and Nyeri Counties were randomly selected out of the five Counties. The forest stations in each of these Counties were stratified and clustered on the basis of their AEZ and composition of plantation species, resulting to four and three clusters in Kiambu and Nyeri Counties respectively. The first cluster of Kiambu County comprised of Thogoto and Muguga. The second one comprised of Uplands, Kerita and Kinale. The third cluster comprised of Ragia, Kamae and Kieni while the fourth one comprised of Kimakia. The first cluster of Nyeri County comprised of Kabage, Kiandongoro and Zaina. The second cluster comprised of Chehe, Hombe, Gathiuru and Kabaru while the third one comprised of Naromoru and Nanyuki.

The first and second clusters of forest stations in Kiambu County were randomly selected resulting to sampling of Muguga, Uplands and Kinale forest stations. Stratification and simple random sampling were used among three clusters (Aberdare range, Windward and leeward sides of Mt. Kenya) at Nyeri County, resulting to random selection of Kabage, Kabaru and Naromoru forest stations.

Soil sampling from selected forest plantations

Soil was sampled from six subplots of 4 m by 5 m established at the four edges and middle of the main plot of 20 m by 50 m (Figure 1) for all the selected tree species and age categories at different study sites. In each of the six subplots, central point was chosen where soil samples were collected at 0 to 20, 20 to 50 and 50 to 80 cm depth using soil augur. Any surface vegetation material was removed before soil augering was done. The collected soil samples from the six subplots of the same depth were thoroughly mixed and a composite sample of about one kilogram was packed into polythene bags for laboratory analysis of carbon, soil pH, nitrogen, phosphorous and potassium. Litter fall was collected from the same area of the soil sampling subplots, thoroughly mixed and about 300 to 500 g was packed into polythene bags for analysis of N and C.

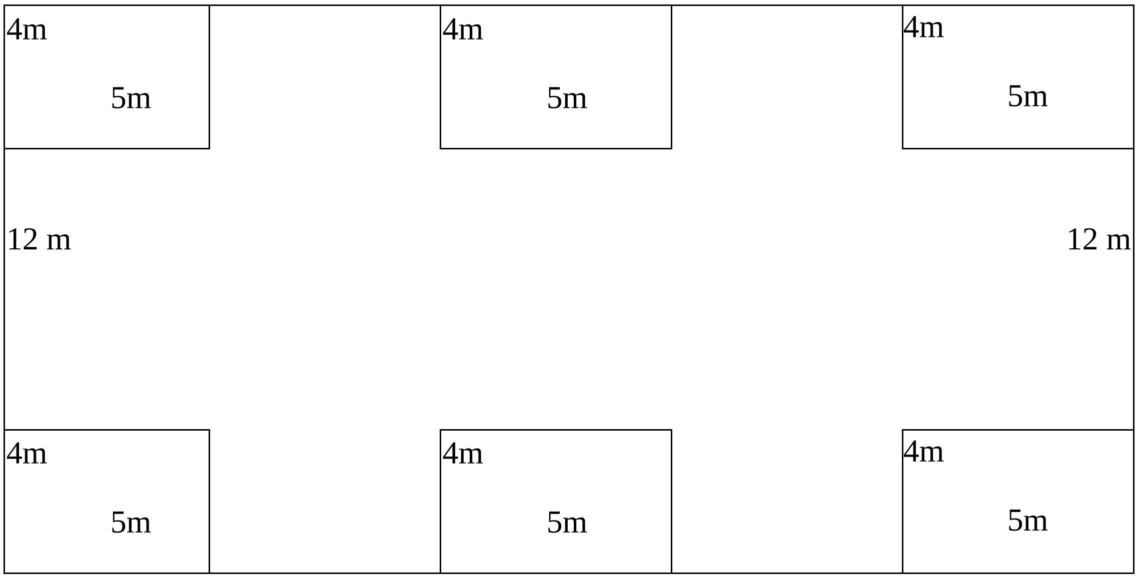

Figure 1. Layout of temporal forest plantation plots for soil sampling and tree measurements of various tree species at different ages

Analysis of soil samples, litter fall and above-belowground biomass

Soil samples were analysed for carbon (C), nitrogen (N), phosphorous (P), potassium (K) and soil pH. Litterfall was analysed for C and N. All analytical methods were conducted using the procedures as described by Okalebo *et al.* (2002). Statistical comparisons were done for C, N, P, K and pH under different soil depths and species using ANOVA and analysis of covariance. Pairwise comparisons were done using orthogonal contrasts. Total soil carbon estimated per ha was based on soil bulk density and percentage of carbon analyzed from soil samples. This was given by;

$$\text{Total soil carbon (ha)} = (\text{Bulk density (kg/m}^3\text{)} * \text{soil depth} * \%C) * 100$$

Where the soil bulk density was determined using procedures as outlined by Okalebo *et al.* (2002). Mean comparisons of carbon sequestered were done using least significant difference (LSD), which was obtained by multiplying twice the standard error of difference (s.e.d) based on linear mixed model approach.

Above and below-ground biomass was estimated using CO2FIX 3.1 modelling framework (Oeba *et al*., 2017; Oeba *et al*., 2016; Masera *et al*., 2003).

Results

Estimation of soil carbon sequestration among selected tree species in different sites

There were significant differences ($F_{(4,271)}$ =8.08; $p<0.001$) in the amount of soil carbon sequestered by commonly grown plantation species adjusted for age at Kiambu, Nyeri South and Nyeri North. *Pinus patula* had the highest amount of soil carbon (191.1 ± 12.55 MgC ha^{-1}) followed by *Cupressus lusitanica* (169.3 ± 12.55 MgC ha^{-1}) at Lari sub county, Kiambu. *Eucalyptus saligna* had the least amount of soil carbon at Kiambu and Nyeri South except in Nyeri North (Table 1).

Table 1. Estimation of soil and above & below ground carbon sequestered by commonly grown plantation species at Kiambu, Nyeri North and Nyeri South

Site	**Tree species**	**Mean soil carbon (MgC ha^{-1})**	**Above and below ground biomass (MgC ha^{-1})**
Kiambu	*Cupressus lusitanica*	169.3	98.4
	Eucalyptus saligna	109.7	79.9
	Pinus patula	191.1	87.2
Nyeri North	*Cupressus lusitanica*	70.1	62.5
	Eucalyptus saligna	83.2	55.5
	Pinus patula	70.2	145.6
Nyeri South	*Cupressus lusitanica*	104.4	91.8
	Eucalyptus saligna	62.3	247.9
	Pinus patula	135.4	72.7
s.e.d		**12.55**	**44.4**

Moreover, mean comparisons in the amount of soil carbon sequestered by the species among sites showed a significant difference ($p<0.05$) in the quantity of carbon sequestered by *Cupressus lusitanica* and *Pinus patula* in Kiambu, Nyeri North and Nyeri South. Similarly, there were significant differences ($p<0.05$) in the amount of soil carbon sequestered by *Eucalyptus saligna* among the sites except for Nyeri North and Nyeri South. *Eucalyptus saligna* had generally lower amount of soil carbon sequestered among the sites as compared to *Pinus patula* and *Cupressus lusitanica* except in Nyeri North. Subsequently, mean comparisons of soil carbon sequestered among species within each site, differed significantly ($p<0.05$) in Kiambu and Nyeri South.

Estimation of % C and selected soil elements across depths among different species

There were significant differences ($F_{(8, 271)}$ = 3.91; $p<0.001$) in the amount of soil carbon across study sites and soil depths among tree species (Table 2).

Table 2. Mean soil carbon sequestered (MgC ha[1]) at different soil depths by among species in Kiambu, Nyeri Noth and Nyeri South

		Mean soil carbon sequestered (MgC ha^{-1}) at different soil depths		
Site	**Tree species**	**0 to 20 cm**	**20 to 50 cm**	**50 to 80 cm**
Kiambu	*Cupressus lusitanica*	84.8	180.2	245.4
	Eucalyptus saligna	69.1	125	136.4
	Pinus patula	96.9	193.8	285.4
Nyeri North	*Cupressus lusitanica*	60.2	74.7	75.9
	Eucalyptus saligna	53.3	79.2	117.9
	Pinus patula	57	100.3	54
	Juniperus procera	29.4	48.1	74.4
Nyeri South	*Cupressus lusitanica*	78.3	91.5	143.9
	Eucalyptus saligna	29.4	56	102.4
	Pinus patula	56.1	141.5	211
	s.e.d	**21.55 (14.22)**		

* In parenthesis is the s.e.d for *Juniperus procera*

There also were significant differences ($F_{(2, 224)} = 79.22$; $p<0.001$) in the levels of soil pH among the sites (Table 3). Kiambu soils were slightly acidic (6.11) as compared to Nyeri North (5.14) and Nyeri South (5.15), which were strongly acidic with a standard error difference of 0.093. Overall, the soil pH in all the study areas was mainly acidic. The levels of acidity varied among species, between and within sites from very strongly acidic to very slightly acidic. The soil under *Cupressus lusitanica* plantations exhibited almost same soil pH at Kiambu, Nyeri North and Nyeri South similar to *Eucalyptus saligna* plantations. However, the soil under *Pinus patula* plantations, which is known to grow well in acidic conditions, had low amount of acidity in the soil in Kiambu as compared to Nyeri North and Nyeri South.

Table 3. Mean estimates of C and major soil elements across soil depths among different species in the study sites

Site	Tree species	Soil depth (cm)	pH	% C	% N	P_ppm	K_ppm	Bulk density (g/cm^3)
Kiambu	*C. lusitanica*	0-20	6.08	4.52	0.74	7.29	407.4	0.94
		20-50	6.23	3.67	0.62	1.68	406.5	0.97
		50-80	6.14	3.12	0.49	3.02	435.7	0.98
	E.saligna	0-20	5.87	3.4	0.59	3.23	605.5	1.05
		20-50	5.91	2.18	0.45	2.39	597.7	1.16
		50-80	5.88	1.48	0.31	0.51	563.9	1.14
	P. patula	0-20	6.27	5.12	0.83	8.90	397.4	0.94
		20-50	6.30	3.81	0.60	4.42	317.4	1.03
		50-80	6.28	3.49	0.50	4.08	313.9	1.02
Nyeri North	*C. lusitanica*	0-20	5.59	3.11	0.58	18.90	326.2	0.99
		20-50	5.42	1.52	0.41	9.18	376.0	1.00
		50-80	5.42	0.91	0.27	8.27	363.4	1.02
	E. saligna	0-20	4.51	2.93	0.62	14.04	214.7	0.90
		20-50	5.00	2.31	0.36	9.16	167.6	0.96
		50-80	5.02	1.77	0.39	7.94	137.1	0.92
	P. patula	0-20	4.85	2.92	0.42	9.73	288.3	0.96
		20-50	4.85	1.98	0.34	8.06	323.0	1.04
		50-80	5.34	0.67	0.24	4.79	265.3	1.06
	J. procera	0-20	6.07	1.46	0.52	7.85	457.6	1.04
		20-50	5.74	0.94	0.45	8.41	346.4	1.03
		50-80	5.63	0.93	0.28	11.04	317.2	1.00
Nyeri South	*C. lusitanica*	0-20	5.35	4.38	0.57	6.65	544.9	0.89
		20-50	5.21	2.05	0.44	7.48	557.5	0.89
		50-80	5.03	2.08	0.43	5.75	475.5	0.86
	E. saligna	0-20	5.74	1.76	0.43	3.10	357.0	0.85
		20-50	5.15	1.22	0.35	4.76	308.0	0.91
		50-80	5.03	1.38	0.74	7.10	303.2	0.91
	P. patula	0-20	4.89	3.44	0.75	5.58	254.1	0.83
		20-50	4.98	3.28	0.65	4.70	254.7	0.88
		50-80	4.93	3.30	0.49	5.22	262.9	0.83
	s.e.d		0.274	0.456	0.098	2.46	93.79	0.058

On the other hand, the interaction effects between sites and species were significant ($F_{(4, 271)}$ = 12.62; p<0.001) with respect to C. Also there were significant interaction effect in C ($F_{(8, 271)}$ = 2.08; p=0.037) between environmental sites, tree species and soil depths. This was however different for *Juniperus procera* whose interaction effect was only between age and depth albeit non-significant ($F_{(4, 48)}$ = 0.23; p=0.918).

The amount of soil nitrogen between sites, tree species and soil depths differed significantly ($F_{(8, 221)}$= 2.00; p=0.047). This was different for *Juniperus procera* whose significant interaction effect was only between age and depth ($F_{(4, 24)}$ = 4.86; p=0.005). Similarly, the amount of soil nitrogen differed significantly ($F_{(2, 221)}$= 13.66; p<0.001) among sites with Kiambu having the highest at 0.57 % followed by Nyeri South (0.54 %) and Nyeri North (0.41 %) with a standard error difference of 0.470. Equally, there were significant differences ($F_{(2, 221)}$= 3.52; p=0.031) in the amount of nitrogen among the tree species with *Pinus patula* having highest amount (0.55 %) followed with *Cupressus lusitanica* (0.52 %) and *Eucalyptus saligna* (0.47 %) with a standard difference of 0.033.

Consequently, amount of nitrogen varied significantly ($F_{(2, 221)}$= 22.80; p<0.001) across soil depths. The highest (0.63 %) was observed at 0 to 20 cm followed by 20 to 50 cm (0.48 %) and 50 to 80 cm (0.43 %) with a standard error difference of 0.032. There were also significant differences on the interaction ($F_{(4, 221)}$= 6.05; p<0.001) of N between environmental sites, tree species and soil depths (Table 3).

The amount of P significantly varied ($F_{(2, 219)}$= 3.50; p=0.032) among the species with *Cupressus lusitanica* having the highest P (7.16 ppm) followed by *Pinus patula* (6.13) and *Eucalyptus saligna* (5.34 ppm) with a standard error difference of 0.819. There were also significant differences ($F_{(2, 219)}$= 12.83; p<0.001) in amount of P across soil depths, which reduced with increase in depth, 0 to 20 cm (8.51 ppm), 20 to 50 cm (5.40 ppm) and 50 to 80 cm (4.90 ppm) with a standard error difference of 0.800. The significant differences ($F_{(2, 259)}$= 13.39; p<0.001; s.e.d =31.44) with respect to K (ppm) among sites were observed with Kiambu having the highest (447.4 ppm) followed by Nyeri South (385.8 ppm) and Nyeri North (281.6 ppm). Equally, significant differences ($F_{(2, 259)}$= 10.01; p<0.001; s.e.d 31.24) in K were found in *Cupressus lusitanica* (412.3 ppm), *Eucalyptus saligna* (368.8 ppm) and *Pinus patula* (302. 8 ppm) plantations. The bulk density significantly differed ($F_{(2, 271)}$= 35.71; p<0.001; s.e.d =0.019) across sites with Kiambu having the highest (1.01 g/cm^3) followed by Nyeri North (0.98 g/cm^3) and Nyeri South (0.87 g/cm^3) with a standard error difference of 0.019. Bulk density also significantly differed across soil depths, 0 to 20 cm (0.94 g/cm^3), 20 to 50 cm (0.99 g/cm^3) and 50 to 80 cm (0.98 g/cm^3).

Discussion

The differences of soil carbon sequestered among species could be associated with various factors such as production of litter, amount of leaf-litter fall, rate of decomposition of leaf-litter, amount of lignin found in leaf-liter, age of the plantation, climatic conditions, plantation management, fire incidences and type of soil among others. Specifically, plant litter decomposition is valuable in the formation of soil organic matter, the mineralization of organic nutrients and the carbon balance in terrestrial ecosystems where it has been established that 53 % of the total carbon is in the organic layer of the soil stored (Austin and Ballare, 2010, Yigini and Panagos, 2016 and Wellbrock *et al*., 2017). The production of leaf litter and its decomposition is species dependent. For example, a study conducted by Demessie *et al.* (2012) showed production of litter under broad-leaved plantation species and natural forest was significantly higher than that under coniferous species. Similarly, the variation of the rate of decay of litter among different tree species may be explained by the amount of lignin in the leaves of the selected species as well as amount of moisture in the soil. Research has shown that biotic decomposition in mesic ecosystems is usually negatively correlated with the concentration of lignin, a group of complex aromatic polymers present in the plant cell walls that is recalcitrant to enzymatic degradation and serves as structural barrier impeding microbial access to labile carbon compounds (Austin and Ballare, 2010). Overall, lignin plays a very important role in the carbon cycle, sequestering of atmospheric carbon into living tissues of woody vegetation. There exists variation on lignin content in the leaves of coniferous and broad leafed trees. A study conducted by Rahman *et al.* (2013) established that the lignin content in the litter of *Pinus Sylvestris* and *Pinus conotrta Dougl* were 29.3 % and 37 %, respectively, as compared to broadleaf tree like *Eucalyptus grandis* that was 21.1 %.

The higher amount of soil carbon sequestered by *Pinus patula* in this study as compared to other species may be associated with high amount of carbon in the leaf-litter fall catalyzed by rate of decomposition as influence by environmental factors such as rainfall and temperature. This was well manifested with differentials of the amount of carbon found in the leaf-litter of *Pinus patula* (46%), *Cupressus lusitanica* (41 %) and *Eucalyptus saligna* (43 %). Sites that were generally receiving low amount of rainfall, had less soil carbon, like the case of the dry part of Nyeri North had the least soil carbon as compared to other sites. Less amount of soil moisture essentially hinders microbial activities in carbon fixation and mineralization of soil nutrients.

Other studies conducted by Lemma *et al.* (2007) have shown differences in the amount of soil carbon sequestered by plantation species such *Cupressus lusitanica, Eucalyptus grandis* and *Pinus patula*. In their study, *Cupressus lusitanica* had highest amount of soil C followed with *Pinus patula* and least with *Eucalyptus grandis* due to litter quality input and rate of decomposition. Palviainen et al. (2010) also showed that Scots pine had higher amount of C on decomposing wood and bark as compared to spruce and birch in Finland. Series of studies have also advanced the same understanding following simulation in CENTURY and YASSO models where they have indicated that accumulation of soil organic pools were driven by changes in litter inputs, rate of decomposition, management regimes, root activity, stand growth rates among others. Specifically, plantation management practices like pruning, thinning, liming, drainage, clear felling and timber harvesting among others could also bring the variations on the amount of C as leftovers would decompose differently depending on the site characteristics and on the litter quality of the material (Liski *et al.*, 2002, Liski *et al.*, 2005, Amichev *et al.*, 2008; Stevens and Wasemael., 2008; Schulp *et al.*, 2008; Johnson, 2010; Eaton and Lawrence, 2009; Kim *et al*., 2016;Wellbrock *et al*., 2017 and Bardulis *et al.*, 2017).

The significant variations of the percentage C across soil depths, decreased with, increasing soil depth. This implied that more C is concentrated in the top layer of the soil where there is high organic matter due to high amount litter fall that decomposes within the top layer of the soil. The amount of SOC at the top layer of the soil, about 1 m depth varies depending on the ecosystem and microbial activities as influenced by abiotic and non-abiotic factors. In arid and semi-arid areas, amount of SOC in the upper layer is estimated to be about 30 tons/ha whereas in organic cold regions is estimated to be about 800 tons/ha (Djukic *et al*., 2018). Overall studies most studies have reported C storage and concentration increased in the upper layers of the soil and decreased with soil depths among hardwood and softwoods tree species in different forest types (Versterdal *et al.*, 2002; Paul *et al.*, 2002; Sierra *et al*., 2007; Eaton and Lawrence, 2009; Weishampel *et al.*, 2009; Dowell *et al.*, 2009; Ngo *et al.*, 2013; Vicharnakorn *et al.*, 2014; Wellbrock *et al.*, 2017 and Djukic *et al*., 2018). In this study, it was also found SOC varied with age of tree where young forest stands had higher soil carbon as compared to middle aged. This may explained by different rates of decomposition that is characterized by at least two stages, where the first stage is described by leaching of soluble compounds and by decomposition of solubles and non-lignified cellulose and hemcellulose resulting to 0-40 % of mass loss as compared to late stage that encompasses the degradation of lignified tissue. This may further be explained by incidences of fire outbreak resulting to increase of ash that is rich in exchangeable bases, which leads to the reduction of soil acidity. Antibus and Linkins III (1992) reported the effect of lime in shifting the ectomycorrhizas in red pine plantations. Ectomycorrhizas are significant component of the forest floor in red pine plantations and produce high levels of surface acid phosphate activity. Therefore induced lime has the potential to alter the mineralization of organic P and P nutrition of the host. Overall, quantification of soil carbon among different soil depths showed an increasing trend due to multiplier of soil depths and bulk density.

The bulk density increased with increase of soil depth in most of the commonly grown plantation species. Kaumbutho and Simalenga (1999) reported bulk density normally tends to increase with soil depths due to low organic matter, poor structure, low moisture and roots penetration as well as pressure exerted by overlying layers. The significant amount of N in *Pinus patula* as compared to *Cupressus lusitanica* and *Eucalyptus saligna* may be explained by effect of forest floor leading to large differences in turnover rates of litter fall and the amount of soil organic matter accumulated in the soils. Studies have revealed that a low C/N ratio of broadleaves led to a better humus layer status (Wellbrock *et al*., 2017). The N quantities may also be influenced by amount of lignin in different species that has a great effect on the nitrogen dynamics of forest ecosystems as well as other ecological processes (Rahman *et al.*, 2013). For instance, the rate at which forest litter decomposes forms an important aspect of assessing past, current and future carbon and N responses of forests under changing climate conditions. Also the litter decomposition entails physical and chemical processes that reduce litter to carbon dioxide, water and mineral nutrients that is regulated by a number of biotic and abiotic factors (Zhang *et al*., 2008; Rahman *et al*., 2013). N comes mainly from three sources, namely; uptake from the soil, foliar uptake of atmospheric deposition and internal reallocation from one organ to another (Wamelink *et al*., 2009). Thus increased N deposition causes an increased rate of soil organic matter. Also in the study by Palviainen *et al.* (2010) on carbon and nitrogen release from decomposing Scots pine, Norway Spruce and silver birch stumps found that N was released considerably more slowly from the stumps than from the stems and branches. However, Foster and Morrison (2002) reported forests respond to increased N availability by increase in stand leaf area and net photosynthesis and increased stem growth. This concurs with Vesterdal *et al*. (2008) who reported mineral soil N status among tree species were strongly related to liter fall N status and was significantly higher in 0 to 30 cm of soil depth.

The findings on other selected soil parameters concurred with soil classifications within Central Kenya, which are known to be largely nitisols. These are characterized by pH <5.5 due to leaching of soluble bases and high clay content >35 % (Gachene and Kimaru, 2003). Therefore the correlation of soil pH with P indicated the levels at which these elements would be available to plants to support the plant growth and accumulation of biomass for enhancement of carbon sequestration. Both sites, C, N, P and K were high. This indicated high amount of precipitation and soil mobilization as influenced by different trees species, thus availability of major nutrients for tree uptake/forest productivity. Soil pH usually has a big influence on the uptake of minerals (Gachene and Kimaru, 2003). Thus soils with high acidity do not provide good conditions for the microorganisms that are very valuable with litter decomposition and other dead wood for nutrient fixation and carbon sinks.

The positive relationship between C and N showed available N could also be used as an indicator of soil carbon sequestration. This is because deposition of N on forests may increase C by increased growth and accumulation of soil organic matter through increased litter production or N-enriched litter. This leads to reduced long term decomposition rates of organic matter. Other studies have shown such relationship between C and N and offered appropriate explanations including large differences in turnover rates of foliar litter fall, forest management, and different tree species among others. Also the increase in nitrogen deposition on forests over a longer period of time may reduce the decomposition of organic matter (Hopmans *et al*., 2005; Mol Dijkstra *et al.*, 2009; Pelster *et al*., 2009; de Varies *et al*., 2009; Wamelink *et al*., 2009; Wellbrock *et al*., 2017). In general, this showed that soils in various plantation forests in Central Kenya had a huge potential of soil carbon stocks for mitigation of climate change. For instance, Hopmans and Elms (2009) found levels of soil C and N declined during the second rotation of

Pinus radiata and ratios of C/N in the surface soil increased from 27 to 30 in lower quality sites and from 24 to 26 in higher quality sites.

Implications of soil carbon differentials on sustainable development mechanisms

The findings from this study collaborates well with a series of studies demonstrating the potential role of SOC in climate change mitigation through sequestration of atmospheric carbon dioxide, thus providing a long lasting solution on sustainable on reduction of greenhouse gases in a less cost effective manner. This calls for strengthening of afforestation of agricultural soils and management of forest plantations to enhance SOC stock through sequestration as influenced by interaction between climate, soil, tree species and management as well as the rate of chemical decomposition of the litter. In order to harness this potential, the inclusion of SOC in the sustainable mitigation mechanisms especially in afforestation and reforestation programmes to tap the forest carbon offset markets under Clean Development Mechanism (CDM) and voluntary mechanism will spur social-economic growth and environmental sustainability. This will resonate well especially with Paris Agreement (PA) where parties agreed to reduce the rising temperature below 2^0C above-preindustrial levels. The implementation of this Paris Agreement is based on the understanding that countries confirmed their intention to share reductions according to common but differentiated responsibilities and respective capabilities. This is reflected in the proposed Nationally Determined Contributions (NDCs) that need to be explored opportunistically on the role of SOC in the overall investments on mitigation options fronted by countries that have signed Paris Agreement.

Further, the evidence demonstrated in this study points to landscape-based approach in addressing SOC as an important sink that need to be mainstreamed in the NDCs and utilize the existing global climate financing such as Green Climate Fund and other incentives to spur sustainable development in the context of combating negative effects of climate change. For example, pushing for SOC in the Sustainable Development Mechanisms with well-developed structures can result to significant investments in the forest sector to enhance carbon stock and sustainable management of forests. This will in turn promote other related sectors of the economy such as agriculture, trade, energy among others through various functions of forests and tree-resources in social-economic development of the nation. In this sense, the future of SDM will rely on strengthening its flexibility in addressing various sustainable options of reducing greenhouse gas (GHG) emissions as fronted by various parties to Paris Agreement. This will result to increased incentives based on different schemes that countries can tap to reduce their vulnerability to climate change and improve on mitigation efforts for sustainable development.

Conclusion and recommendations

The role of forest SOC in reducing atmospheric GHG is apparent in many studies. It was also evident that different species sequester different amounts of carbon depending on abiotic and non-abiotic factors. The potential carbon sink by forest plantations as presented in this study cannot be underestimated in their overall contributions to climate change mitigation. The national based initiatives on afforestation and reforestation programmes to improve the forest cover, like the current call by the national and county governments of the republic of Kenya will certainly results to increased carbon sink. This will work well when the governments also continue to promote other alternatives to livelihoods in order to minimize the leakages on carbon footprints. The realization of the contribution of SOC at a global scale will therefore require strengthening of policy and institutional frameworks to support investment in the forest sector. This study therefore recommends for setting up reliable baseline emissions scenario from the forest sector taking into account the contribution of SOC as source and sink. In this manner, appropriate quantification/measurement, monitoring, reporting and verification will be institutionalized to ensure total valuation of the contribution of forest sector in climate change mitigation as reflected in various implementations options of Nationally Determined Contributions. This is important because, soil organic carbon dynamics are usually driven by the changes in climate and land cover or land use, calling for the need to strengthen the integration of LULUCF and AFOLU interventions in various NDCs options.

Acknowledgement

We thank the Kenya Forestry Research Institute (KEFRI) Board of Management for allocated funds to undertake this study. We thank the following KEFRI technical support staff: Thomas Ondieki, James Mwaura, George, Omolo, Shadrack Odhiambo, Mary Gathara, Paul Kibera and Samuel Kamonde among other staff for their role they played in soil sampling, soil analysis and other related logistics during and after field work. We are also indebted to Kenya Forest Service staff, who were very helpful during sampling and data collection. Our sincere gratitude goes to unknown reviewers and editorial team that shaped this paper for effective scientific communication. Finally, we appreciate the financial support from African Forest Forum (AFF) in sponsoring the lead author and co-author from the Secretariat to participate and present the findings in the 5th Kenya Forestry Research Institute (KEFRI) Scientific Conference.

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Local Community's Perception of Forest Ecosystem Services in Mau, Cherengany and Mt. Elgon and Implications for Management

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Abstract

Forest ecosystems provide ecological, economic, social and health benefits. Despite the importance of forest ecosystems to livelihoods and maintenance of ecosystem resilience there is continued degradation caused by burgeoning population, agricultural expansion, poor governance, climate change and unsustainable land uses. One major driver of forest degradation is lack of appreciation of ecosystem values and low perception of forest ecosystems by diversity of stakeholders. Current conservation discourse recognizes the integration of local views and perception of forest Ecosystem Services (ES). Understanding local community perceptions of forest ES is therefore critical in crafting viable conservation strategies/ management plans sensitive to livelihoods of the local people. This study investigated forest ES; their importance to local communities, threats and current and future flow in Mau, Cherangany and Mt. Elgon forest ecosystems. The study collected data using Participatory Rural Appraisal methods (Focus Group Discussions, Stakeholders meetings and key informant interviews) to identify the ES. The identified forest ES were ranked in a participatory exercises using weighted ranking method (Pebble Distribution Method (PDM). Twenty-five ES were identified and water provision ranked the highest with importance value of between 15 % and 24 % in the 3 ecosystems. Water was also identified as the only ES that is important today, and in10 years to come. This paper provides a clear understanding of local perception of ES values which is critical in influencing the behavior of the local people and in enabling incorporation of local values in management plans and policies.

Key words: Ecosystem Services, Importance Value, Livelihoods, Perception

Introduction

Everyone in the world depends on Earth's ecosystems and the services they provide, with forests providing ecological, economic, social and health benefits (MEA, 2005 and Richards, 2012). Kenya on the other hand is highly dependent on natural resources through the services they provide which assume diverse values, they can be grouped as: provisional, ecological and social and cultural services. Provisional services include food, water, raw materials (fibre, timber, fuel wood) and medicine which have direct use value. Ecological services include both regulating and supporting functions associated to indirect use value; and lastly social and cultural services such as aesthetic and recreational which assume nonuse value (MEA, 2005; Nahuelhual *et al*., 2007). However, severe degradation due to population pressure, expansion of agricultural land, poor governance, climate change, unsustainable land-use practices and lack of appreciation for the critical role of forests in improving human wellbeing have threatened the sustainable provision of goods and services which has subsequently jeopardized the value of ecosystems (FRA, 2000).

Most efforts in conservation have focused more on identifying the most important spots for management as biodiversity surveys. However, the information generated usually has little impact on most decisions which reflect diverse issues. The technical approach to conservation is by involving the most relevant stakeholders in decisions which balance biodiversity conservation and incorporates the values and preferences of stakeholders, especially the local forest dependent communities for them to likely succeed. In the past there has been little or no effort in seeking the views of the local perception (Lynam *et al*., 2006).

In most forest management, the desires and the objectives of forest industry are clear and easily understood by forest managers. However, to local communities, needs and perception "remain veiled" to most outsiders unless a specific effort is made to understand them (Scott, 1998). Understanding stakeholders' knowledge and perception about ES, from different contexts, provides a valuable means of gaining insight into the opportunities and constraints that face ES management in a multiuser landscape (Urgenson *et al.,* 2013). This is necessary to facilitate the implementation of strategies that are aimed at improving the capacity of the poor to draw vital ES from landscapes. Rather than viewing people as a 'threat 'to conservation, where the development objectives of local communities are seen to be in direct conflict with the objectives of biodiversity conservation, there is need for new approaches that portrays communities as potential partners in biodiversity conservation (Adams & Hulme, 2001; Guthiga, 2008).The local perception of ES values is key in influencing the behavior of the local people and in enabling the incorporation of local values in management plans/policies to ensure that there is sustainable utilization of ecosystem services. This study was therefore undertaken to determine the perception of local communities towards ES values and the perceived distribution of interests. This was achieved by identifying all ecosystem services enjoyed by local communities from the water towers and ranking them according to their perceived value and importance of the ecosystem services today and in future. The study also sought to identify specific beneficiaries of these services, and articulated contextual issues and specific threats to the ecosystem.

Research Methods

Study Area

The study was conducted in three major water towers of Kenya namely Mau forest complex, Cherangany forest ecosystem and Mt Elgon forest ecosystem (Figure 1).

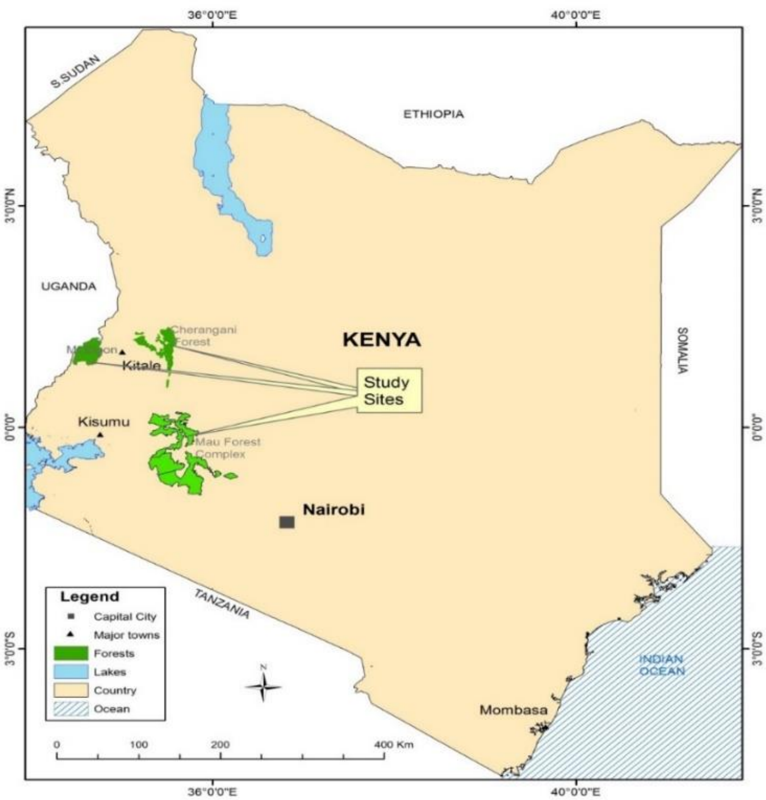

Figure 1. Location of Mau Complex, Cherangany Hills and Mt Elgon ecosystems in western Kenya

Mau Complex

Mau Ecosystem situated at 0°30’ South, 35°20’ East within the Rift Valley Region and spans seven counties: Baringo, Bomet, Keiyo-Marakwet, Kericho, Nakuru, Nandi, and Narok, it forms the largest closed-canopy montane forest ecosystem in East Africa covering approximately 400,000ha.The ecosystem is the main catchment area for 12 rivers draining into Lake Baringo, Lake Nakuru, Lake Turkana, Lake Natron and the Transboundary Lake Victoria (Nabutola, 2010). Mau complex being the largest indigenous forest vegetation in the area has varied vegetation with scattered trees in the plains to shrub land and forests to the hilly uplands. The species diversity has sacred and cultural values to indigenous communities such as the Ogiek who have lived in the forest and practice a hunter and gatherer lifestyle. The complex supports wood based industries and trade and many local communities are dependent on forest resources for livelihoods (Nabutola, 2010; Olang and Kundu, 2011; Langat *et al*., 2016).

Cherangany Forest Ecosystem

Cherangany forest is located within an area defined at 1°16’ North 35°26’ East, it comprises of forest reserves totaling 114,416.2 ha which transverse 3 counties of Elgeyo/Marakwet, West-Pokot and Trans-Nzoia Counties. It sits between major basins; Lake Victoria and Lake Turkana which are fed by two major rivers of Nzoia River and Kerio River respectively, the latter gets its waters from streams in the east while the former from west streams. The ecosystem has attractive recreation sites of Mtelo campsite, Kipteber Mountain, Muyein waterfalls, Kipkoboi caves, scenic viewpoints, game reserves and water sports. It is home to diverse flora and fauna with some being endemic such as the *Capysjuliae* butterfly which may attract scientist from across the world (KFS, 2015).

Mt Elgon Ecosystem

Mt Elgon ecosystem lying between 0°52' and 01°25'N, and between 34°14' and 34°44'E is an extensive trans-boundary resource between Kenya and Uganda with an approximate area of 400,000ha, 114,416.2ha in the Ugandan and 180,000 ha in the Kenyan side, it covers 2223 Sq. Km of which 1078 sq. km is on the Kenyan side (SGS Qualifor, 2007; Kipkoech *et al*., 2011; KFS, 2015). The ecosystem is an important regional resource that supports local economies through direct and indirect uses. The ecosystem provides biological, aesthetic, tourist, cultural, forest resources, educational, employment and carbon sink values which are significant and could mitigate poverty and likely negative impacts of climate change (SGS Qualifor, 2007). Mt. Elgon ecosystem is a habitat to 37 "globally threatened" species (22 mammals, 2 insects and 13 bird species) and is also home to 9 endemic animals, making the area a priority for species conservation. Two hundred and forty bird species have also been documented and include: Alpine chat, long crested eagle, cape robin chat and yellow whiskered green bulbul. A total of 67 reptiles and amphibians and 179 species of butterflies are documented from Mt Elgon region (Larsen, 1991; Davenport, 1996; Makenzi P.M, 2016).

Despite their significance, the three Water Towers are facing immense challenges which include: encroachment, conversion to agricultural land and human settlement, overgrazing, forest fires and illegal harvesting and growing conflicts (KFS, 2015).

Data Collection

Participatory Rural Appraisal Methods were used in data collection which involved Focus group discussions and key stakeholder's meetings with different approaches used to obtain specific data using a prepared checklist.

Key stakeholder's forums and Expert meetings

Stakeholders were pooled from key government agencies (Kenya Forest Services, Water Resource Management Authority, Kenya Wildlife Service, water service providers and Universities), County governments (Nakuru, Kericho, Elgeyo Marakwet, Uasin Ngishu, TransNzoia and Bungoma) Private Organisations (saw millers and tea plantations and forest products traders) and Civil Society Organisations (NGOs and Local CBOs). Four meetings were carried out to identify key ecosystem services, contextual issues and threats to the ecosystem.

Community Meeting

Community meetings were held in study sites of Mau (South West Mau), Mt. Elgon (Kaboywo), and Charangany (Toropket) involving (FGDs) which included local administrators (village elders), Community Forest Association (CFA) officials, Water Resource Users Associations (WRUAs) officials, religious leaders, and key community leaders (men, women and youth). In South West Mau, two FGDs were held at Chemare and Sotit with 15 and 20 participants respectively. Whereas, in Cherangany and Mt Elgon FGDs were conducted in Kimnai with 30 participants and in Kaptama with 40 participants respectively. Discussions focused on the history of the ecosystem, products and services as well as seasonal fluctuations and their relative importance to different stakeholders, as well as threats.

Ranking of Ecosystem Services

Through Focus Group Discussions in community meetings and stakeholder's forum identified goods and services were ranked using the weighted ranking method (Pebble Distribution Method) (Lynam *et al.,* 2006). The method utilized counters with the approach that; the least important service was given one counter and thereafter other goods and services scored relative to that service. Community members discussed among themselves as they redistributed counters until they were satisfied. The method was greatly utilized in the study to not only rank the ecosystem services but also the seasonal availability of ES, levels of threats, and level of benefits received from the ecosystem by various stakeholders.

Results and Discussions

Identification and ranking of ES by local communities

Twenty-five (25) ES were identified across the three ecosystems as highlighted in table 1. The Pebble Distribution Method (PDM) by Lynam *et al*., 2006 was then used to determine the relative importance value (RIV) of the identified E.S.

$$\text{Relative Importance Value (RIV)} = \frac{\text{Relative weight (Counters)}}{\text{Total Weight (Counters)}}$$

Services perceived to be very important were those with direct use value with water ranking the highest greater than 15 % in the entire ecosystem, followed closely by firewood and pasture. Maize which is a staple food in Kenya was ranked among the most important ES in Mt. Elgon. The Kenya Forest Service has introduced the Plantation Establishment for Livelihood Improvement System (PELIS) where the forest adjacent communities are allocated land in clear felled areas for growing of annual crops for own use. This arrangement benefits both parties (local communities in terms of land for growing food crops and KFS in terms of reducing plantation establishment costs. 'Other ES ranking over 5 % in more than two ecosystems were; medicine, timber, air quality and honey. The perceived importance of provisioning values is likely due to the fact that these values go into direct household consumption or directly support other economic activities. The findings are consistent with other studies where provisioning services were usually valued most, although differences are seen on importance of specific ES in different regions (Rodriguez *et al.* 2006).

In addition, there may be lack of awareness on intricate linkages between household livelihood activities and other intangible values (indirect and non-use values (regulation and supporting functions) hence their low values. Air quality, a regulatory value is valued more with over 6 % in Mau and Cherangany ecosystem as compared to the other cultural, supporting and regulating values, this is consistent with a study by Zhang *et al.* 2015 and could be attributed to the much heightened awareness on pollution and importance of trees in reducing greenhouse gases from the environment. The fact that the community did not identify most regulating, supportive and cultural values highlighted in the MEA 2005 such as soil formation, nutrient cycling, regulation of disease and pests, and pollination and flood regulation means that they do not appreciate the services and will impact negatively on management of the ecosystem for such services.

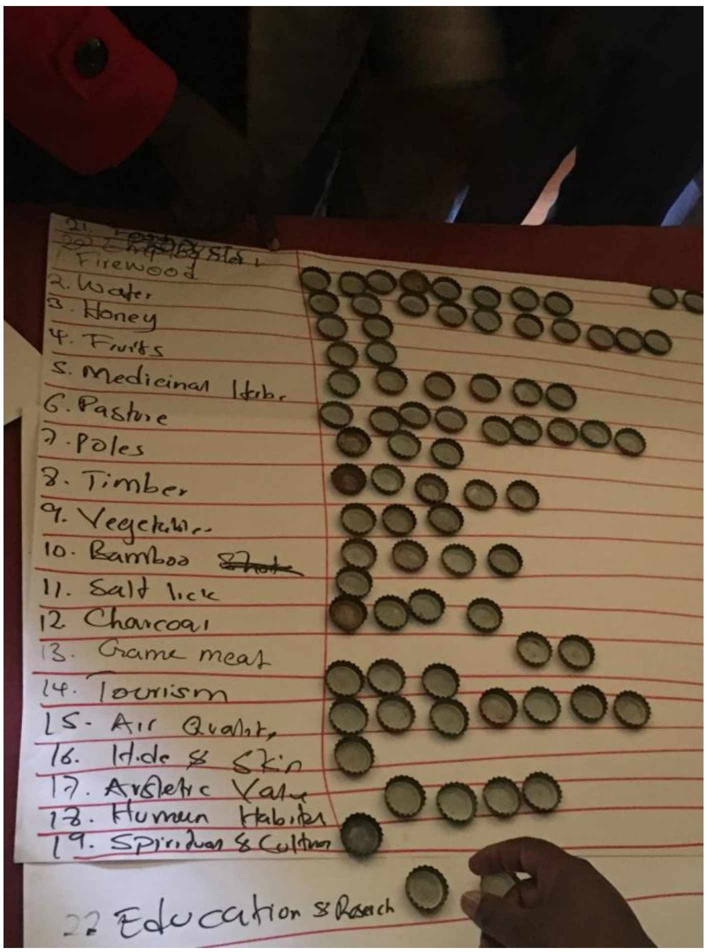

Figure 2. Community members determining the relative importance value of key ES using the Pebble Distribution Method in Kaboywo in Mt Elgon

Table 1. Ecosystem services and their relative importance value to local communities

ES type	Ecosystem Services	Relative Importance Value		
		Mt. Elgon	**Cherangany**	**Mau**
Provisioning	Water	0.15	0.20	0.18
	Firewood	0.12	0.14	0.08
	Fodder/Pasture	0.10	0.12	0.08
	Maize	0.08		
	Medicine	0.06	0.10	0.10
	Timber	0.05	0.12	0.03
	Bamboo Shoots	0.04		
	Charcoal	0.04		
	Employment	0.04		
	Poles	0.03		0.06
	Vegetables/Mushrooms	0.03		0.03
	Honey	0.02	0.06	0.06
	Game meat	0.02		0.02
	Salt lick	0.01		
	Hides and skin	0.01		
	Fruits	0.01	0.04	0.03
	Twinning material		0.04	0.03
	Agricultural Tools			0.03
	Thatch grass			0.02
Aggregate		**0.81**	**0.82**	**0.75**
	Tourism	0.03	0.06	0.02
	Aesthetic	0.03		0.06
	Education and research	0.02		
Cultural, education	Cultural/Ceremonial sites	0.01	0.04	0.05
Aggregate		**0.09**	**0.10**	**0.13**
Regulation	Air quality	0.07	0.04	0.06
Supporting	Habitat- Biodiversity	0.03	0.04	0.06
Total		**1.00**	**1.00**	**1.00**

Table 2 summarizes main products extracted from the forest throughout the year and the months mostly extracted. Some products and services such as water, pasture, air quality, habitat-biodiversity, aesthetic value and water flow and air quality regulation are considered equally important throughout the year. Use of forests for cultural purposes occurs in the month of December when traditional initiation ceremonies takes place. There is variation in the use of forest for various products and services due to product seasonality (e.g. mushroom, fruits, honey etc.) depending on rainfall patterns and flowering of specific plants and food scarcity on farm these is in line with (Sunderland, 2011) who declares forests as an important repository of food and other resources that can play a key role in contributing towards food security. It is notable that there is enhanced use of forest for game meat during dry months. Firewood is also extracted more during the months of July, August, November and December which attract a number of festivities and when family labor is high during school vacations where child labor is utilized by local households in firewood accumulation, these is consistent with (Cooke, 2000) who suggest that collection of certain resources among them being fuel wood is predominantly undertaken by children and women in most rural communities who base their livelihoods on environmental resources.

Though some products were collected all through the year across the 3 ecosystems, it was noted that extraction was high in some months. Medicinal plants, for example, are collected more during drought when dust conditions are high, as well as at the onset of rains and when maize has flowered and there is a lot of pollen in the air, leading to allergies, flu and sickness in general. For fodder, more livestock browse the forest in the dry seasons and during the onset of planting.

Table 2. ES extracted from the forest with respect to months of extraction and magnitude (numbers indicate relative weight of use across months)

Products/services		**Months of the year**											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Food crops	Mt Elgon						0.05	0.15	0.1	0.1	0.15	0.20	0.25
	Cherangany	0.40	0.30	0.30									
Timber	Mt Elgon	0.40	0.30	0.30									
	Cherangany	0.10	0.10	0.20						0.10	0.10	0.20	0.20
	Mau	0.15	0.04				0.08	0.08			0.23	0.23	0.19
Bamboo Shoots	Mt Elgon			0.20	0.50	0.30							
Vegetables/ Mushrooms	Mt Elgon	0.10			0.40					0.50			
	Mau	-	-	-	0.40	-	-	-	0.40	-	-	-	0.20
Honey	Mt Elgon		0.70										0.30
	Cherangany	0.20	0.20	0.20							0.10	0.10	0.20
	Mau	0.21	0.37	0.29									0.12
Game Meat	Mt Elgon				0.60				0.40				
	Mau	0.13	0.37	0.5									
Hides and Skin	Mt Elgon				0.40				0.60				
Fruits	Mt Elgon			0.4					0.2				0.4
	Cherangany	0.2	0.2	0.1								0.2	0.3
	Mau	0.15	0.35	0.15	0.35								
Medicine	Cherangany	0.3							0.2			0.1	0.4
Fibre	Cherangany	0.2	0.1	0.1						0.1	0.1	0.2	0.2
Agricultural Tools/ farm inputs	Mau		0.19	0.22	0.11							0.26	0.22
Poles	Mau	0.15	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.31	0.19
Tourism	Mt Elgon								1.0				
	Mau	0.10	0.15	0.25	0.5								
Thatch grass	Mau	0.10			0.25	0.15					0.20	0.30	

Local community's perception on distribution of benefits from forest ecosystems

Five categories of beneficiaries were identified by the community across the three ecosystems. Table 3indicates the perceived magnitude of benefits appropriated from the three forest ecosystems by various stakeholders. All ES were cited to benefit local communities with an exception of tourism in Mau and Mt. Elgon, which is perceived by local communities to benefit only government and foreigners. In Cherangany, there is established sports tourism and most local and international athletes visit high altitude sports center which have visible impacts on local communities. Tourism in the other two ecosystems of Mau and Mt. Elgon was not perceived of importance to local people mainly because most local communities do not perceive any direct linkage between international tourisms and their well-being. For a long time, forest conservation has been promoted in official circles as a means of earning foreign exchange and this may have influenced local communities to feel alienated from this benefit. Other products like manure and thatch grass are perceived to exclusively benefit the local people, even pasture in Cherangany benefits only the local community. The government benefits were in form of revenue, licenses fees and permits while traders on the other hand benefited more from trade in; mushrooms, agricultural tools, charcoal, honey, timber and medicine.

Table 3. Ecosystem Services and perceived distribution of benefits to stakeholders from three ecosystems

Products/ Services	Ecosystem	Local people	Saw millers,	Traders	Government	Foreigners
Water	Mt Elgon	0.50		0.10	0.20	0.20
	Cherangany	0.30			0.50	0.20
	Mau	0.57	0.14	0.21	0.07	-
Firewood	Mt Elgon	0.50		0.30	0.20	
	Cherangany	0.66		0.16	0.18	
	Mau	0.60	-	0.20	0.20	-
Charcoal	Mt Elgon	0.40		0.60		
Pasture	Mt Elgon	0.90			0.10	
	Cherangany	1.00				
	Mau	0.50	-	0.33	0.17	
Timber	Mt Elgon	0.15		0.45	0.35	0.05
	Cherangany	0.6		0.06	0.34	
	Mau	0.62	0.15	0.23	-	-
Wild game	Mau	0.54			0.31	0.15
Honey	Cherangany	1.00				
	Mau	0.64		0.36		
Agricultural tools and basketry	Mt Elgon	0.70		0.30		
	Cherangany	0.65		0.35		
	Mau	0.60	-	0.40	-	-

Products/ Services	Ecosystem	Local people	Saw millers,	Traders	Government	Foreigners
Mushrooms and vegetables	Mt Elgon	0.45		0.55		
	Cherangany	0.50		0.50		
	Mau	0.55	-	0.45	-	-
Twining material	Cherangany	1.00				
	Mau	0.41	0.41	-	0.18	-
Fruits	Cherangany	1.00				
	Mau	1.00				
Medicine	Mt Elgon	0.70		0.15	0.15	
	Cherangany	1.00				
	Mau	0.64	-	0.36	-	-
Air quality	Mt Elgon	0.55		0.15	0.25	0.05
Biodiversity	Cherangany				0.6	0.4
	Mau	0.12	-	0.08	-	-
Cultural sites	Cherangany	1.00				
	Mau	1.00				
Wild break	Mt Elgon	0.60			0.10	0.30
	Cherangany	0.60			0.20	0.20
	Mau	0.30	0.10	0.10	0.30	0.30
Tourism	Mt Elgon				0.4	0.6
	Cherangany	0.26			0.50	0.24
	Mau				0.50	0.50

Perception of threats to forests by local communities

Main threats to the forest were identified and ranked from the most significant to the least significant. Overdependence on the forest, overgrazing due to overstocking, encroachment, pests and diseases, illegal harvesting of forest goods and fire were identified as the most significant threats (Table 4). Poverty was cited as one of the main threats in Mau yet it was not mentioned in the two other ecosystems but manifestations of poverty (deforestation, illegal harvesting) are highlighted. This could be because poverty is a main underlying cause of overdependence in forest resources this is with regard to previous studies among them a study by (Soltani *et al* 2014), which describe the Zagros community in Iran which is characterized by poverty and a long history of forest utilization and forest degradation highly dependent on forest resources for their livelihood.

Table 4. Relative magnitude of forest ecosystem threats as perceived by local communities

	Ecosystem		
Threats	**Mt. Elgon**	**Cherangany**	**Mau**
Fire	0.15		0.03
Encroachment	0.15	0.26	0.07
Illegal Harvesting/ Poaching	0.05		0.15
Poverty			0.08
Pests and Diseases		0.18	0.02
Grazing/overstocking	0.20	0.22	0.02
Charcoal Burning			0.13
Low staffing			0.07
Corruption by government officials			0.03
Perception of Low Value			0.07
Climate change		0.14	0.05
Population growth/ settlements		0.06	0.08
Pollution	0.05		
Deforestation/ overdependence	0.30		
Technology (power saws)			0.02
Demand for wood products	0.30	0.30	0.07
Invasive species	0.20		0.10

Identification and ranking of ES by stakeholders

Key stakeholders held discussions to identify forest ecosystem services (ES) and their relative importance today and in the next 10 years so as to inform on management priorities. Most important ES were weighted five (5) with the least important weighted one (1). As shown in (Table 5) only water supply was identified as most important now and will remain as important 10 years to come in all the ecosystems. Most supportive and regulatory services were perceived as less valuable today but will be more valuable in future; these can explain the lack of appreciation of their current value as highlighted in Table 1. Fodder, fuelwood, wood products, timber and agricultural uses are among the ES perceived to reduce in value in the next 10 years. The services /products diminished importance in future is because people are likely to find substitutes for these ES.

Table 5. Ecosystem services and the stakeholders' perceived importance values to society

		Importance (0-5), 5 being the most important					
		Now			Next 10 years		
	Ecosystem service	Mau	Mt. Elgon	Cherangany	Mau	Mt. Elgon	Cherangany
Provisional	Fodder	3	3	3	2	3	3
	Food	3	3	3	3	3	3
	Fuelwood	4	4	4	2	3	3
	Water supply	5	5	5	5	5	5
	Hydro power generation	3	0	1	4	1	3
	Medicinal	3	2	2	4	3	3
	Honey Harvesting	5	1	1	5	2	2
	Wood products	4	4	2	4	3	1
	Timber	5	4	4	3	4	4
	Agriculture use (food)	3	5	5	3	4	4
	Biodiversity conservation	5	4	4	5	4	4
Cultural	Tourism and recreation	5	2	2	5	4	4
	Aesthetic	2	2	2	4	3	3
	Cultural and spiritual	3	1	1	2	1	1
	Education and research	3	2	2	4	4	4
Regulatory	Air purification	4	4	4	5	4	4
	Regulation of Water Flow	4	4	4	5	5	5
	Climate regulation	3	4	5	5	5	5
	Water Purification	3	2	2	5	5	5
Supportive	Soil conservation	4	4	4	5	5	5
	Pollination	5	3	3	5	4	4

Conclusion and Recommendations

The findings of our study have a number of policy implications and therefore, decision making on sustainable management of these ecosystems can be anchored on these derived importance values. Policy makers including county and national government should therefore take full consideration of the spatial and temporal ecosystem service provisioning in national and county development plans. The importance of understanding community dependence on forests when making decisions about natural resource management cannot be overlooked. The ways in which households rely on forests as well as threats to those benefits vary across space and time. The output from the study can inform the decisions on community dependence and ecosystem resilience and enhance the development of sustainable forest management which incorporates benefit sharing arrangements through public participation (PFM), as highlighted in Kenya Vision 2030 and forest policy which can be realized and be integrated in the participatory management plans of these water towers.

The perception of enjoyed values also provides the basis for structuring alternative livelihood programs that are geared towards reducing pressure to the ecosystem. They also provide for a platform to engage with local communities in conservation efforts, where the managers can identify gaps in knowledge among the stakeholders for purposes of awareness creation or even collaboration.

Acknowledgement
We acknowledge the Center for International Forestry Research (CIFOR) in Nairobi and the Kenya Forestry Research Institute (KEFRI) for facilitating and coordinating activities related to this work. We also appreciate the United States Agency for International Development (USAID) for funding this work and to the US Forest Service (USFS)-International Programs for the technical support. Much appreciation goes to the local communities and administrators in Mau, Cherangany, and Mt. Elgon who took part in the surveys. We thank other agencies and organizations (KFS, KWS, WRMA, WSB, WSP, KWTA) and County government, Civil Societies and private institutions who took part in the survey. Lastly, we acknowledge Mr. Geoffrey Maina (Egerton University) for the georeferenced maps and all other professional peers and specialists in various fields, not named here, but whose expert opinions informed this study.

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Indigenous Traditional Knowledge on Landscapes, Biodiversity use in Mt. Elgon Forest Ecosystem and Implications for Conservation

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Abstract
Forest biodiversity underpins ecosystem functioning and the generation of benefits that support multiple dimensions of local livelihoods. The integrity of forest ecosystem is shaped by communities' uses, traditional knowledge and practices. Because community participation is critical in management of conservation areas, it is essential that resource managers and policy makers understand local traditional knowledge, biodiversity use to inform appropriate interventions. This study was undertaken to document traditional indigenous knowledge on landscapes, biodiversity uses and their impacts. It formed part of a wider study meant to develop forest restoration efforts to enhance flow of ecosystems services and livelihoods of local communities in Mt. Elgon forest ecosystem. The study used Participatory Rural Appraisal (PRA) techniques (community meetings, Focus Group Discussions (FGD) and Key Informant interviews) to capture traditional indigenous knowledge on landscapes, forest biodiversity uses and their importance to local livelihoods. Types of landscapes and biodiversity uses were free listed and importance value assessed using weighted ranking method (Pebble Distribution Method (PDM). The information obtained was cross referenced with published literature. Twelve landscapes were identified as important to local people and their associated faunal and floral species. Fifteen plant and ten animal species were ranked in order of importance to local communities. These forest biodiversity resources provide human health, shelter, cultural and spiritual wellbeing and cash income. This study has shown that forest biodiversity is important to the local livelihoods and local people have wealth of traditional knowledge on forest biodiversity, uses and management practices. Although traditional knowledge is gradually declining because of socioeconomic and cultural change; it is imperative to integrate some of this knowledge in forest management.

Key words: Traditional indigenous knowledge, Biodiversity, Livelihoods

Introduction

Forest biodiversity underpins ecosystem functioning and the generation of benefits that support multiple dimensions of local livelihoods. The integrity of forest ecosystem is shaped by communities' uses, traditional knowledge and practices. Most conservation strategies seldom integrate local indigenous knowledge and aspirations of the local people and this has created friction between communities and resources managers (Berkes, 2004). There are opportunities for mitigating these conflicts by tapping into local indigenous knowledge particularly on uses and conservation (Biswas, 2003). The integration of indigenous knowledge is critical in ensuring community participation in resource management as articulated in Kenya constitution (Chapter 5 Article 69(1c) and Forest Conservation and Management Act 2016. Application of indigenous knowledge and values of biodiversity by local communities are increasingly being recognized globally as important ingredients for crafting viable biodiversity conservation strategies (Biswas, 2003). This is because integration of such indigenous knowledge into conservation programs facilitates knowledge sharing, trust building and enables constructive engagement among stakeholders. It also instills shared vision, ownership and responsibility towards achievement of goals. Integration of indigenous knowledge and practices can build social capital (local support) goodwill, adoption and promote and provide sustainable insurance against conflicts (Smith and Pretty, 2003). Furthermore, it may assist in achieving the dual goal of conservation and sustainable community development (Otieno and Analo, 2006). Studies have shown that local people are more knowledgeable than outsiders because of their long association with and; use of biodiversity are firmly ingrained in their local cultures and values (Smith and Pretty, 2003; Kala, 2009; Rainforest Foundation, 2012). The indigenous knowledge of the local people has remained largely ignored and untapped in Kenya and therefore accumulated knowledge for biodiversity conservation is scanty. Mt. Elgon forest ecosystem is one of the critical Water Towers in Kenya. However, it is threatened by anthropogenic activities, yet it is a reservoir of flora and fauna diversity of immense potential. Past studies have indicated that local communities have encroached on about 10,000ha (Ochuoga, 2002). If the biodiversity of this ecosystem is not documented and integrated into conservation measures, the indigenous knowledge and potential value will be eroded. Because community participation is critical in management of conservation areas, it essential that resource managers and policy makers understand local traditional knowledge, biodiversity use to inform appropriate interventions. This study was undertaken to: determine the important values of different landscapes to the local people, to identify biodiversity and ecosystem services critical for livelihoods, to explore indigenous ecological knowledge (uses and management practices). This Paper outlines the important role of forest biodiversity to local livelihoods and the need to incorporate indigenous knowledge in sustainable management and use of plant resources. Some of the important landscapes and biodiversity use (plant and animal) suggests ways of integrating indigenous knowledge in conservation and restoration of degraded forested landscapes.

Materials and methods

Study sites

Mt. Elgon forest is one of the key water towers and is distinguished by rich biodiversity but threatened by agricultural encroachment, illegal poaching of valuable floral and faunal resources and other anthropogenic impacts. The ecosystem lies between 0°52' and 01°25'N, and between 34°14' and 34°44'E (Figure. 1). It is an extensive transboundary resource between Kenya and Uganda covering 2,223 square kilometers, of which 1,078 square kilometers fall on the Kenyan side. The ecosystem covers an area of about 772,300 hectares made up of 221,401 hectares of protected areas and 550,899 hectares of farmlands and settlements of which 180,000 hectares of the forest are in Kenya. The forest is an important regional resource that supports local economies through direct and indirect uses. In addition, the ecosystem provides biological, aesthetic, touristic, cultural, educational, employment, resource, and carbon sink values that are significant and could mitigate poverty and the likely negative effects of climate change.It is habitat to 37 “globally threatened” species (22 mammals, 2 insects, and 13 bird species) and is also home to 9 endemic animals. The alpine chat, long-crested eagle, Cape Robin-chat, and yellow-whiskered greenbul are among the 240 documented bird species. A total of 67 reptiles and amphibians and 179 species of butterflies have also been documented in the Mt. Elgon region (Larsen, 1991; Davenport, 1996; Makenzi, 2016). The forest hosts many plant species such as Elgon teak, Indigenous bamboo etc. making the area a priority for species conservation.

This study was undertaken using key informants and stakeholders adjacent to Kaberwa and Kaboywo forest blocks of Mt. Elgon forest ecosystem. The sites were selected based on preliminary assessment and discussions with key informants Kenya Forest Service (KFS) and Community Forest Association (CFA).

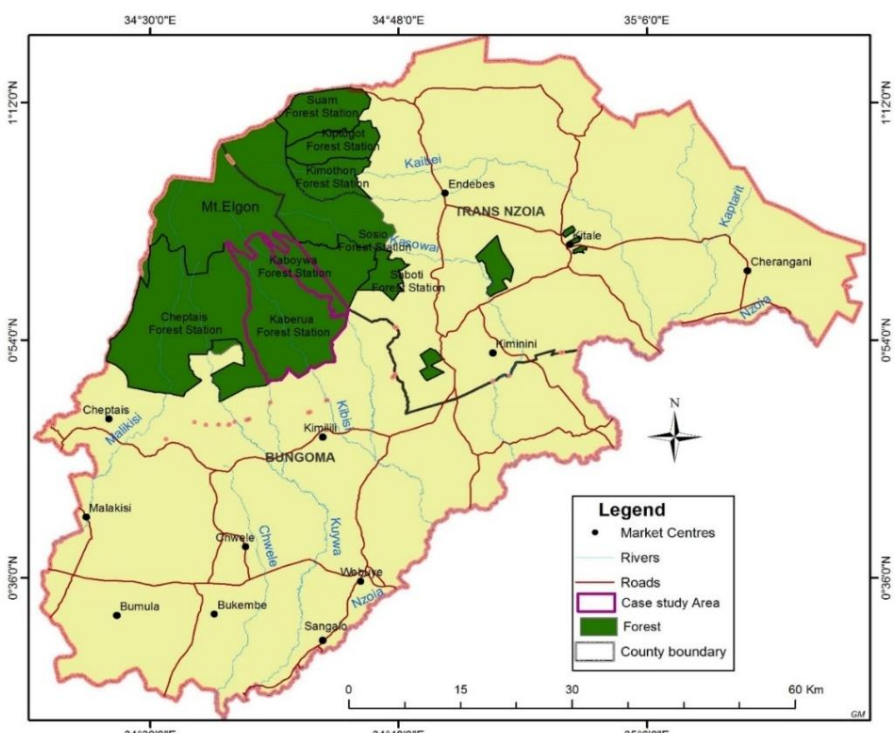

Figure 1. Mt. Elgon ecosystem selected case study forest blocks and forest adjacent villages)

Data collection

Purposive sampling was used to select key informants. Twenty-two key informants (one key informant from each sampled village) were selected based on the following criteria: familiarity with the area and the local people, and having a broad and in-depth knowledge about his/her village, its households and the forest issues in general and age (Old men and women people > 50) years and specialized resource users were targeted for the Focus Group Discussion. The selection of key informants was screened with the assistance of officers from Kenya Forest Service (KFS) and local CFA and local opinion leaders. Local organizations such CFAs, Community based organization (CBO), Water Resources Users Association (WRUA) and government agencies (KFS and KWS) participated in the study. Indigenous knowledge on biodiversity was obtained through historical and ecological reconstruction of the past through story telling. The Knowledgeable persons were given the opportunity to narrate while encouraging others to contribute. All the landscapes, forest products and services, important plants (tree) and animals important for local livelihoods were free listed during the meetings. Pebble Distribution Method was used to rate the importance of the above items using 50 bottle tops, where participants were asked to distribute amongst the various items of interest based on perceived important value at community level. The participatory ranking exercise was led by one person from the community while researchers acted as facilitators. The outcome of participatory ranking was completed through consensus (Poffenberger *et al*., 1992; Hughes and Dumont, 1993; Sheil *et al*., 2002; Lynam *et al*, 2006).

Data analysis

The data obtained from FGD were triangulated with secondary sources. The importance value was computed using the formula below:

$$I_v = \frac{PDM\ Score}{Total\ PDM\ scores} * 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where I_v is the importance value

Results and discussions

Local knowledge on landscapes, characteristics and their perceived importance

The local communities have developed local indigenous knowledge because of their long association which can be harnessed in developing sustainable use strategies of biodiversity resources. Local communities ranked the importance of different landscapes using PDM method (Sheil *et al*., 2002; Lynam *et al*., 2006). The summary of the participatory ranking exercise is shown below in table 1.

Plate 1.Participants rating importance of landscape types using Pebble Distribution Method

Table 1. Local important value of different landscape in Mt. Elgon as perceived by local community (PDM)

Name		Perceived importance	Importance Weight	Relative Importance Value
Common	Local			
Hills	Legemosiek	Security site/ watch tower, Training of athletes, Grazing ground, Rainfall attraction, Harvesting of natural herbs	4	0.08
Mountain	Tulondok	Source of rivers, Tourist attraction, Habitat for wildlife, Hunting sites, Herbal medicine source, Cultural sites	5	0.10
Flat plains	Ketowoosiek	Grazing, Resting places, Recreational site, cultivation and human habitat	5	0.10
Wetlands	Saoset	Source of thatching grass, Source of water, Planting tuber crops, Source of small rivers, Sites for bee keeping, Cultural sites, Source of reeds for basketry	2	0.04
Rivers	Aonosiek	Source of water for domestic and anima use, Marking boundaries, Water for irrigation, Source of fish, Swimming, Pumice for scrubbing feet, Cultural sites (rites of passage)	5	0.10
Forest	Wooget	Source of firewood, medicinal herbs, Timber, Habitat for wild animals, Farming, Honey production, Tourism, Rain attraction, Source of seedlings, Grazing area, community security, Habitat for flora and fauna, Source of medicinal herbs, Cultural sites	12	0.22
Settlement	Rorokosiek	Boundary markings between residents and forests, Geo-referencing point, Administrative units, Livestock rearing, Establishment of schools and hospitals, Churches and mosques, Market centres	8	0.16
Caves	Kebonosiek	Salt lick, Security- Hiding places, Habitat for wild animals, Tourist attraction, Recreation, Source of water and minerals	3	0.06
Valleys	Ronkosta	Making roads, agricultural land, grazing, Decorative clay	2	0.04
Escarpments	Rengeriet	Marks boundaries between upper and lower zones, Medicinal herbs, Habitat for wildlife and plants, Tourist attraction (aesthetic), Waterfalls – Tapping area for water	3	0.04
Forest edge	Marmarta	Grazing, Demarcation of forest and settlement, Roads, Fire line	1	0.02
Total			50	1.00

Forested landscapes are highly valued, followed by settlement areas, mountains, flat plains and rivers which are rated important for livelihoods. The perceived importance of the forest is reflected in the importance values attached to the forests as sources of products and services to the local community (Table 1).This implies that forests are threatened and there is need for effective management by determining which species are preferred locally and can therefore be successfully adopted into conservation plans. It is important as well to understand the attitudes of the community towards tree conservation and their willingness to adopt agroforestry technologies aimed at establishing individual and community woodlots for fodder, fuelwood, timber and other forest product needs. Failure to do this will lead to loss of important traditional tree resources and this will put livelihoods of the local community at stake and increase poverty levels.

Forest products and services from Mt. Elgon

Forest ecosystem is perceived by the local community as of primary importance as: human settlement, source of posts, animal grazing, firewood and water. The human settlement ranked high and this is a source of concern for the survival of the forest. The locals see the forest as reserve land to be occupied by the community and they believe the forest is rightfully theirs. It has therefore been subjected to various human pressures generated by human activities in agriculture, logging and a host of other developmental projects. Needless to add, all these activities have led to a steady depletion of the forest resources. Other studies have shown that, the influence of anthropogenic activities on natural forest has been profound particularly on the biodiversity of forest ecosystem (Sayer and Whitmore). This in turn has negative effects that change the quality of stand, microclimate, nutrient cycling and composition of forest species (Kouki, 1994; Kappelle *et al.,* 1995). The next important products from the forest after human settlement are the extractive use values (grazing, poles/posts, firewood, and water (Table 2). The role of forest ecosystem in environmental quality and biodiversity conservation is recognized by the community and this could be a good entry point for introducing good conservation practices and sustainable use of Mt. Elgon. The people of Mt. Elgon are aware of the problems they face in order to provide for their families, to produce sufficient fuelwood for domestic use, together with the need to sustain biological diversity in combination with continuing provision of fodder (Mengich, 1994), fruits, dyes, tannins, gums, resins, and medicines (Cooper *et al.,* 1992). As the population increases, their troubles increase and they are forced to farm marginal land and clear the forest which is vulnerable to degradation and may result in poor crop yields and widespread poverty (Barbier, 1999; Glover and Elsiddig, 2012).

Table 2. Important and Relative Important Values of Forest Products and Services as perceived by local community in Mt. Elgon

Type of use	Products/services	Importance weight	Relative Important Value
Consumptive	Human settlement	6.00	0.12
Consumptive	Grazing	5.00	0.10
Consumptive	Poles/ Posts	5.00	0.10
Consumptive	Firewood	4.00	0.08
Consumptive	Water	4.00	0.08
Consumptive	Medicine/ human and livestock	3.00	0.06
Consumptive	Charcoal	2.00	0.04
Consumptive	Employment	2.00	0.04
Consumptive	Honey	2.00	0.04
Consumptive	Timber	2.00	0.04
Consumptive	Vegetables/mushrooms/bamboo shoots	2.00	0.04
Consumptive	Cultivated foods	1.00	0.02
Consumptive	Source of tree seedlings	1.00	0.02
		39	**0.78**
Non-consumptive	Environmental quality	3.00	0.06
Non-consumptive	Habitat for wild animals	3.00	0.06
Non-consumptive	Cultural sites/ spiritual	2.00	0.04
Non-consumptive	Aesthetic value/ Scenery	1.00	0.02
Non-consumptive	Education and research	1.00	0.02
Non-consumptive	Recreation (Ecotourism)	1.00	0.02
		11	**0.22**
	Total	**50.00**	**1.00**

Knowledge about tree species and their associated ecological zones

According to local communities, there are two identifiable zones namely Mosoop (Upper zone, mountainous areas) and Soil (lower zones-lowlands). Local communities listed tree species associated with different ecological zones (Table 3).

Table 3. Distribution of tree species as reported by local communities in Mt. Elgon

Eco zone (Kooret)		**Tree species**
Common name	**Local name**	**Botanical name**
Upper Zone(Mosoop)	Pegerondiet	*Olea capensis*
	Sabtet	*Podocarpuslatifolia*
	Keterwet	*Juniperusprocera*
	Kormotik	*Prunusafricana*
	Cheptuiyet	*Diospyrosabissinica*
	Luliondet	*Carissa spinarum*
	Masitetet	*Olea capensis*
	Koroshwandet	*Olea europeasspafricana*
	Kibumatet	*Ekerbegiacapensis*
	Simatweet	*Ficusthoningii*
Lower zone (Soi)	Tungurwet	*Flocourticiaindica*
	Chebitet	*Acacia lahai*
	Saonet	*Elaedendaronbuchananii*
	Mushyembut	*Albiziagummifera*

Biodiversity and their importance to livelihood in Mt. Elgon

Plant species important to livelihoods

Ten tree species were identified as important to the local people. Table 4 shows the rankings of the species identified by the community. From the list, the exotic tree species (Eucalypts and Cypress) are perceived to be very important and this is followed by indigenous tree species of *Croton macrostachyus, Olea Africana* and *Prunus Africana*. The importance of the exotics is due to their fast growth and multiple use and market value (Glover, 2012). The indigenous species were also ranked due to their medicinal, cultural and spiritual values. The number of ranked indigenous tree species was quite high indicating the potential use of the species for forest restoration and intensification of trees on farm. Local communities rely on indigenous trees for food, medicine and income. These species also contribute to a cleaner environment as they sequester more carbon compared to exotics species. The collection, processing and marketing of indigenous tree products represents a significant portion of rural household income particularly in areas where farming is marginal (Buyinza *et al*., 2015). Indigenous tree species are becoming scarce due to unsustainable land management practices and destructive harvesting methods. Harvesting products such as medicine from indigenous trees is often destructive and leads to wood deterioration due to insect damage and fungal infection. Developing sustainable harvesting and processing methods will go a long way in ensuring continued supply of valued products from indigenous tree species.

Table 4. Importance value of tree species as perceived by local communities in Mt. Elgon

Botanical name	Local name	Local uses	Importance Value	Relative Importance Value
Eucalyptus spp	Mtimbao	Timber, poles, posts, agricultural tools	10	0.20
Cuppressus lusitanica	Cheparuus	Timber, medicine, shade, ornamental, windbreak	6	0.12
Croton macrostyachyus	Tobosweet	Firewood, charcoal, timber, medicine, bee forage ceremonial, ceremonial	6	0.12
Olea capensis	Pergeriondet	Firewood, timber, posts, medicine,, shade, ornamental	5	0.10
Prunusafricana	Armootit	Timber , firewood, construction, medicine (human and livestock)bee forage, ornamental, shade	4	0.08
Flocourticiaindica	Tungururuet	Firewood, charcoal poles ,tools, fruits nuts medicine, bee forage, mulch ,soil conservation, live fence	4	0.08
Markhamia leutea	Sananteet	Timber, Firewood, artifacts, poles, medicine, bee forage, shade, ornamental, soil conservation, windbreak	3	0.06
Yushania alpina	Tegandet	Fencing, construction, vegetables, Quivers, arrows, containers, walking stick, ceremonial	3	0.06
Juniperus procera	Katarweet	Firewood, charcoal, timber, poles, posts, medicine, tools, beehives, bee forage, ceremonial, ornamental	2	0.04
Podocarpus latifolia	Septeet	Firewood, timber, posts, medicine,, shade, ornamental,	1	0.02
Others	Various		6	0.12
Total			**50**	**1.00**

Important tree species and their sources

The local community listed important tree species and sources in their environment (Table 5). Most exotic species are cultivated (planted) and indigenous tree species (Elgon teak, Cedar, and bamboo and Podos are mostly obtained from indigenous forest. The only species collected from wild sources and not cultivated is *Juniperus procera* and it implies that the species may need special attention in terms of protection and domestication. The other indigenous species have been domesticated in this area; the interventions could focus on promoting on farm intensification of tree species growing to ease pressure from wild sources (natural forest).

Table 5. Sources of priority tree species for products in Mt. Elgon

Tree species name		Where sourced (Score) (RIW)			
Botanical	**Local (Sabout)**	**Wild from forest**	**Cultivated**	**Bought**	**Total**
Eucalyptus spp	Mtimbao		0.6	0.4	1.0
Cuppressuslusitanica	Cheparuus		0.4	0.6	1.0
Olea capensis	Pergeriondet	0.8	0.2		1.0
Croton macrostachyus	Tobosweet	0.3	0.7		1.0
Markhamialutea	Sananteet	0.1	0.9		1.0
Juniperusprocera	Katarweet	1.0			1.0
Prunusafricana	Armootit	0.5	0.5		1.0
Yushaniaalpina	Tegandeet	0.8	0.2		1.0
Flocourticiaindica	Tungururuet	0.2	0.8		1.0
Podocarpuslatifolia	Septeet	0.9	0.1		1.0

Plant species have many functions and uses by the local community and below is the list of medicinal plants of importance to the local people. The list identified by the community as important as medicinal plants was also reported by Okelo *et al*., (2009) and Jeruto *et al*., (2008) (Table 6).

Table 6. Priority Medicinal plants, diseases cures, level of extraction and potential for future use in Mt. Elgon

Botanical name	Local name	Diseases	Parts harvested	Impact on sustainability			Remarks
				Extent of collection	Present stock	Future potential	
Olea capensis	Pegeriondet	STIs, Prostate	Bark, Roots, Leaves	Very high	Very low	Very low	High demand for timber medicinal and charcoal
Bersamaabbysnica	Kibumetet	Diarrhea, Back ache	Bark, Roots, Leaves	Very low	Very low	Very low	
Prunusafricana	Arumwatit	Bloody diarrhea, HIV, Prostate, sex stimulant	Bark, Roots, Leaves	Very high	Moderate	Very low	
Juniperusprocera	Keterwet	Wounds, breathing difficulty	Roots, fruits	Very low	Very low	Very low	The species is threatened by extractions for poles
Croton macrostachyus	Toboswet	Cattle, Malaria, Fever, Diarrhea, Fresh wounds, Snake bites	Leaves, Buds	Very low	Very low	Very low	Makes very good charcoal
Diospyrosabbyssinica	Cheptuiyet	Fluke worms, De-worming	Roots	Very low	Very low	Very low	Rare and to extinct
Ilex mitis	Tongotuet	Fertility disorders, Urinal tract, Appendicitis	Bark, Roots	Low	Low	Very low	Treats multiple ailments and produces quality charcoal
Warbugiaugandensis	Sokwondet	Pneumonia, Colds, Headaches, Cattle, Chicken	Bark, Roots, Leaves	Very low	Very low	Very low	Highly valued for medicine
Acacia lahai	Kamyadet	Tooth ache, Cow diarrhea, Chest pains	Bark	Very low	Low	Very low	Good for construction, very durable in service
Cordia abyssinnica	Mugengeret	Stomach cramps after delivery	Bark	Very low	Very low	Very low	It has light wood
Tecleasimplifolia	Kwiriondet	STIs, Deworming cattle, Backache, Blood cleansing	Roots, Leaves, Bark	Very low	Very low	Moderate	Used as walking sticks and agricultural tools

Animal species and their importance to livelihood

The local community listed 10 important animal species and their importance to livelihoods (Table 7). Elephants, buffalo were ranked as the most important due to its food and nutritional values. Leopard is regarded by the local people for its fur and claws which is believed to confer fierceness and used for traditional rites of passage. Humans have used animals and their products since time immemorial. Animals are used for different purposes including; food, medicines and religious cultural practices. Some studies have shown that use of the surrounding fauna resources occurs mainly among populations within disadvantaged socioeconomic conditions. The extreme needs experienced by these communities often lead to hunting of wild fauna for food purposes (Soares *et al*., 2014).

Table 7. Importance value of animal species to local livelihoods as perceived by community in Mt. Elgon

	Species name		**Importance weight**	**Relative Importance Value**
Common	**Scientific**	**Local**		
Elephant	*Loxodonta africana*	Belionteet	10.00	0.20
African Bufallo	*Syncerus caffer*	Soyeet	8.00	0.16
Leopard	*Panthera pardus*	Meliito	5.00	0.10
Water buck	*Kobus ellipsiprymnus*	Boineet	4.00	0.08
Hare	*Lepus timidus*	Pranguut	4.00	0.08
C. monkey	*Colobus guereza*	Monkosieet	4.00	0.08
Gazelle	*Gazella gazella*	Saramaitaa	3.00	0.06
Dikdik	*Madoqua kirkii*	Ngemweet	2.00	0.04
Monkey	*Cercopithecus hamlyni*	Suboltit	2.00	0.04
Olive Baboon	*Papioanubis*	Kibyongeet	1.00	0.02
Others			7.00	0.14
Total			**50.00**	**1.00**

Conclusion and way forward

This study has shown that forest resources (biodiversity) is important to the livelihoods of the people for provisioning services (Shelter (Timber, posts), energy (firewood and charcoal), health (human and livestock) and as sources of cash income. The local communities have had a long association with the forest biodiversity and have local knowledge in the use and management of biodiversity. Results from the study have shown that plants and animals are very critical in livelihoods of the local people and management plans should integrate the local knowledge and the needs of the local communities. The extractive use of resources has had some negative impacts on biodiversity and any proposed interventions should take cognizant of the socioeconomic dependence of the local people. There are some notable tree species which the communities have identified as threatened such as: Elgon teak (Mt. Elgon), Indigenous bamboo (*Yushania alpina*), *Prunus Africana*, *Podocarpus latifolia* and *Nuxia congesta.* It notable that the decline in biodiversity is driven by population pressure, unemployment, Poverty, unemployment, technological know-how, corruption, market integration (expansion of markets for forest products), agricultural expansion and infrastructure development. This study has shown the important role of forest biodiversity to local livelihoods and therefore there is urgent need to incorporate indigenous knowledge in sustainable management and use of plant resources. The use of forest biodiversity is currently not guided by the nexus between the needs of the people and biophysical needs of the biological resources. It is imperative that concerted action be undertaken involving all stakeholders and taking into consideration the local realities and knowledge.

Acknowledgements
We are grateful to Director KEFRI for the logistical support and EU- Water Towers Project for the financial support. We appreciate the local community of Mt. Elgon, Kapsokwony district for sharing with us their indigenous knowledge.

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Effects of Natural Resource Conflicts on Well-Being of Farmers and Pastoralists in Kilosa and Kiteto Districts, Tanzania

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Abstract

Resource use conflict is a global issue. In sub-Saharan Africa such conflicts can be extreme, leading to deaths. There is a growing literature on the causes and effects of resource use conflicts. This paper investigated the relationship between resource use conflicts and household well-being, and the socio-economic determinants of such well-being (happiness) among farmers and pastoralists in Kilosa and Kiteto Districts, Tanzania. Data were collected through key informant interviews and focus group discussions. In addition, a questionnaire was administered to 373 randomly selected respondents 143 pastoralists and 230 crop farmers. Quantitative primary data were analysed using SPSS and STATA software. Content analysis was used to analyse qualitative data from the FGDs, key informant interview and open ended questions. There was a significant difference ($p < 0.01$) in asset ownership, household dwelling conditions, degree of happiness and education levels between farmers and pastoralists. Female headed, larger, and younger households in conflict ridden areas were more likely to be happy ($p < 0.05$) than their male counterparts; whereas less educated households, and households with better dwelling conditions were less likely to be happy compared to more educated and those with better dwelling conditions. District of domicile influenced degree of happiness among households with those living in Kilosa reported to have been happier than those in Kiteto District. The paper concludes with a recommendation to the government to educate all stakeholders on the threat of resource use conflicts against the well-being of the society and ways to minimize their effects among farmers and pastoralists.

Key words: Conflict, Well-being, Happiness, Farmers, Pastoralists

Introduction

Conflict and low levels of subjective well-being are not a recent development in Africa (Helliwell *et al.*, 2014). In the 1970s, the largest global study of well-being found that African countries produced the lowest ladder of life scores; this means that people in Africa have low level of well-being compared to people in the developed world. The factors that have undermined Africa's potential of achieving happiness and satisfaction in life in the 21st century include endless conflicts, famine, diseases and dictatorship (Helliwell *et al.*, 2014). In this paper, conflict refers to a situation where two or more opposing user-groups are fighting for a particular resource (Adisa, 2011). The most common conflict in Tanzania is that between farmers and pastoralists over natural resource use (HAKIARDHI, 2009).

Well-being is a multifaceted concept which denotes happiness, security, preferences, needs, and relative comparisons (Haywood *et al*., 2005; Helve and Hirrilamin, 2015). The proxy measures of well-being used in this study are threats to personal security and psychological well-being, household assets, condition of the household dwelling, number of years spent in school, and subjective well-being (happiness) of farmers and pastoralists in the study area. Veenhoven (2013) defines happiness as the degree to which an individual judges the overall quality of his or her life as being favorable. Layard (2011) regards happiness as enjoying life and feeling good, and is thus synonymous with subjective well-being (SWB). Well-being, which is measured in terms of the quality of life, is only possible when people's needs are satisfied in all dimensions (QOL) (Sen, 1992). According to literature, (Estes and Van Roy, 1992; Estes, 2007), a person's achievement is reflected in his/her quality of life such as being in good health, education, income, and happiness. Nonetheless, this may also include avoiding escapable morbidity and premature mortality, and having complex achievements including self-respect, and taking part in the life of the community (Sen, 1992).

Generally, living in safe communities is essential for someone's well-being since the feelings of insecurity limit people from engaging in their daily activities (Organisation for Economic Cooperation and Development (OECD, 2011). Also according to Adisa (2011), conflict between farmers and pastoralists has undermined the well-being of these groups by compromising their personal security, education, income, wealth, and civic engagement. Studies in sub-Saharan Africa have established a linkage between conflict and well-being. In Nigeria for example, increased natural resource based conflicts have been associated with negative effects on productivity (Majekodumni, 2014). Similarly, in Kenya insecurity and fear are reported to have reduced the levels of food production at the household level due to the reduction of the quality and quantity of livestock (Kipkemoi *et al*., 2017).

Tanzania has a rich land resource for agricultural development. Nonetheless, out of the country's 94.5 million hectares of land only 44 million hectares are arable and only 24 % of this land is under cultivation. Of the 50 million hectares suitable for livestock production, only 26 million hectares are under use (URT, 2015). Moreover, Tanzania has the largest livestock population of 21.3 million heads of cattle, in Africa after Sudan and Ethiopia. In Tanzania, 85 % of agriculture is dominated by smallholders' farmers and traditional agro-pastoralists who keep an average of 50 heads of cattle (URT, 2015). An empirical study by Chongela (2015) revealed that Tanzania's agricultural sector is the key contributor (accounting for 25.88 %) to the national economy, (crops subsector (18.93 %); livestock subsector (4.7 %) and fisheries subsector (2.25 %). Generally, in 2015, agriculture contributed to 30 % of the export earnings and employed about 65.0 % of the total labour force (URT, 2016). Livestock production contribution to agricultural GDP is 18 % (URT, 2015).

Despite the country's abundance in Natural resources such as land and water, conflicts between farmers and pastoralists are still frequent. In the country's 10-year Agriculture Sector Development Strategy (ASDS II), it is clearly stated that; "the ever increasing conflicts between farmers and livestock keepers are a hindrance to the sector's growth". This statement suggests the severity of incidences of conflict and their effect on the nation and individuals well-being. Farmers in this papers are referred to as people who are involved in the cultivation of land for growing various types of crops (Sigalla, 2013), while pastoralists are people who live mostly in dry remote areas and whose livelihoods depend on their intimate knowledge of the surrounding ecosystem and on well-being of their livestock (Tessema *et al.*, 2014). These people are characterized by mobility involving moving with their herds in search of fresh pastures and water (Semberya, 2014).

Generally, efforts by different stakeholders including the government of addressing natural resource based conflicts between farmers and pastoralists in the country have been in place. However, there have been sporadic attacks in Kilosa and Kiteto for a long time. These attacks have claimed lives of many innocent men, women and children and thus, posing major challenges to their economic, social and psychological well-being (Semberya, 2014). The most notable conflicts include the December 2000 fighting between pastoralists and farmers in Kilosa district which claimed the lives of 38 people in Rudewa-Mbuyuni Village. The December 2008 fight at Kikenge Hamlets of Mambegwa and Mabwegere villages left 8 people dead, several houses burnt, several crops destroyed, and thousands of livestock stolen (HAKIARDHI, 2009; Benjaminsen, *et al.*, 2009; Benjaminsen *et al.*, 2014; IPS; 2014; Mwamfupe, 2015). Likewise, in Kiteto, the January 2014 farmer-pastoralist clashes left 10 people dead, 20 injured, 60 houses burnt and a number of properties including six motorcycles and 53 bicycles destroyed (Benjaminsen, *et al.*, 2014; Makoye, 2014). Moreover, the notorious clashes threatening the well-being of famers and pastoralists have so far been reported in Kilindi, Mvomero, Kilombero and parts of Lake Rukwa Basin (Benjaminsen *et al.*, 2009).

A number of studies have analysed the effects of income on happiness in Sub-Saharan Africa (Ram, 2010; Mahadea, 2013; Steptoe *et al.*, 2015). Nonetheless, little is known in the scholarly literature about the effects of conflicts on well-being specifically how these conflicts affect happiness of the farmers and pastoralists in Kilosa and Kiteto Districts, Tanzania. These groups of people have been victims of land conflicts since 2000. However according to Frey (2011), the reasons as to why few studies have focused on the effects of conflicts on subjective well-being include inadequate data, unclear memory of such conflicts or war episodes, as well as complications accompanying the conflict situations. Therefore, it is important to consider the damaging consequences of natural resource use conflicts on the well-being of farmers and pastoralists. Moreover, understanding how conflicts affect the well-being of the actors is an important step towards the achievement of sustainable peace and development. Unfortunately, the well-being of actors in natural resource based conflicts, especially in Kilosa and Kiteto have not attracted sufficient theoretical and empirical analysis. Therefore, the current study aimed at: (i) determining the effects of conflicts on farmers-pastoralists well-being with regards to personal security, psychological well-being, wealth, housing, and happiness conditions; and (ii) analyzing the factors influencing subjective well-being (happiness) among farmers and pastoralists in Kilosa and Kiteto Districts, Tanzania.

Methodology

Description of the study area and Research design

The study was conducted in Kilosa and Kiteto Districts in Morogoro and Manyara regions, respectively (Figure 1). The Districts were selected because of the prevalence of persistent conflicts between farmers and pastoralists (Makoye, 2017; Ubwani; 2014a). Moreover, Kilosa is often referred to as an area of land scarcity and conflicts in government development reports and in newspaper reporting (Benjaminsen *et al*., 2009). Thus, the District is identified as a conflict hot spot (Massoi, 2015). The study employed a cross sectional research design which entails the collection of data in more than one case at a single point in time (Bryman, 2004). Household data were gathered through a survey questionnaire.

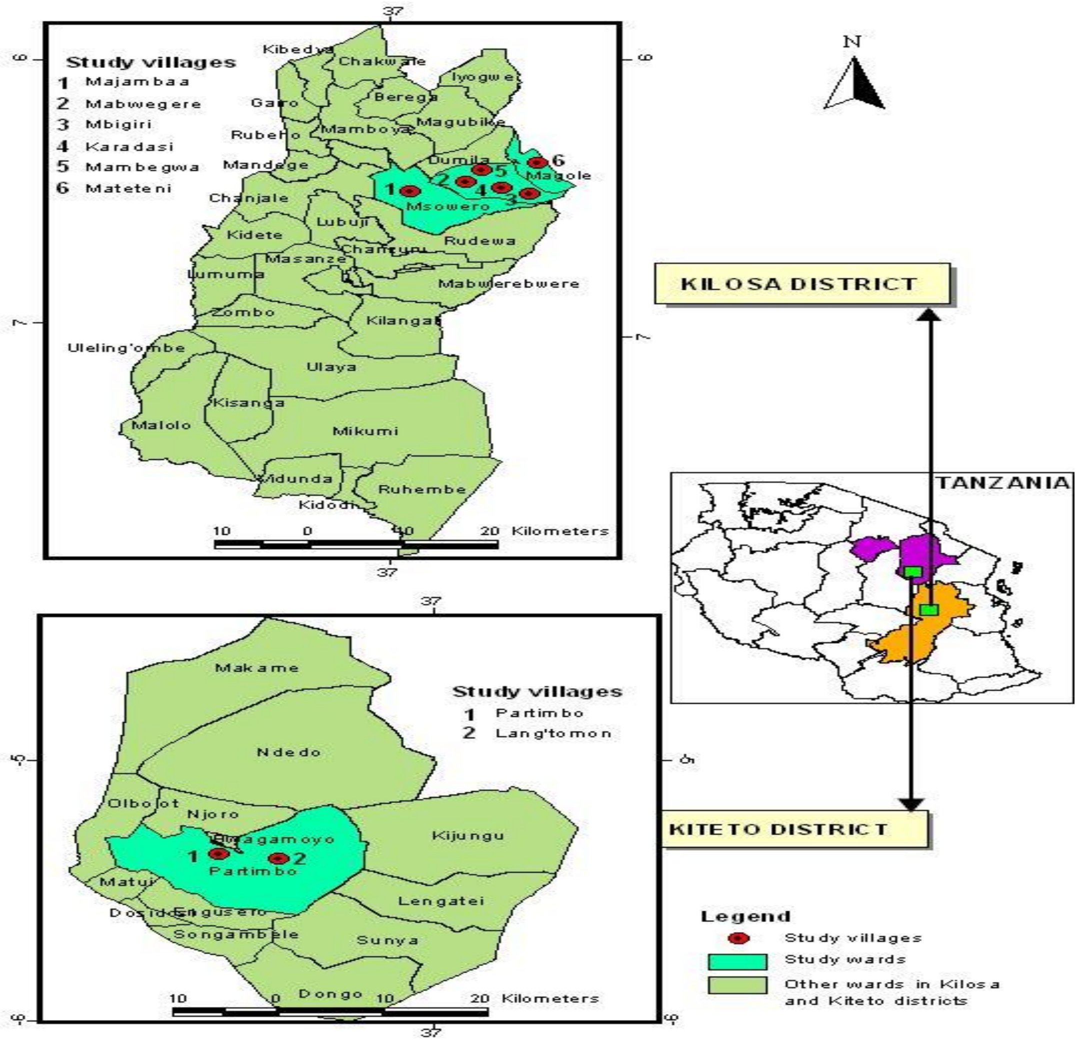

Figure 1. A Map of the study areas in Kilosa and Kiteto Districts, Tanzania

Sampling technique and Sample size

A multistage sampling technique was used to select regions, districts, divisions and wards. First, Morogoro and Manyara regions were selected using purposive sampling technique because these were known as hot spots for natural resource use conflicts. In stage two, Kilosa and Kiteto districts were selected through purposively sampling technique. Moreover, Kiteto and Kilosa are homes to many migrant farmers and pastoralists. In stage three, three wards namely, Magole, Kidete, and Msowero, were purposively selected in Kilosa; and two wards namely, Partimbo and Namelock were purposively selected in Kiteto. In stage four, villages were selected using proportionate sampling technique (Kothari, 2004). Based on this criterion, five villages namely; Mabwegere, Magole, Majambaa, Mfulu, and Karadas were randomly selected in Kilosa and three villages namely, Partimbo, Kimana and Lan'gtomon were randomly selected in Kiteto. Finally, in stage five participating households were selected using simple random sampling technique. Thus, a sample of 228 and 145 households were randomly selected, in Kilosa and Kiteto respectively, making a total sample of 373 households.

Data collection

Each respondent was asked to answer whether he or she strongly disagreed, moderately disagreed, slightly disagreed, slightly agreed, moderately agreed or strongly agreed with each item included in the scale. The scores ranged from 1 for strongly disagree to 6 for strongly agree. Given the difficulty in measuring household income or consumption expenditure due to recall bias, seasonality and data collection burden, the asset-based measures was used as a proxy measure for a household well-being (Vyas and Kumaranayake, 2006). Therefore, household wealth was assessed based on the assets ownership and the sample was categorised into very poor, poor, and non-poor. Nonetheless, this paper takes a wealthier household as one that owned transport, agricultural, livestock, other household assets and a good house. Transport assets included a motorcycle, a bicycle, an ox-cart and a car. Agricultural assets assessed included a hand hoe, a sword/knife, a spade and an ox-plough. Other household assets were an improved cooking stove, a radio, a television, a mobile phone, chairs and mosquito nets. Livestock assets included cows, goats/sheep and poultry. Condition of the dwelling of the household focused on; house ownership, the type of roofing, wall material, floor material and the number of rooms. External conditions of the household dwelling were also used as an indicator of the quality of a household's wellbeing. Each attribute of the household quality scored 1, 2 and 3one is lowest score and 3 is the highest. Indicators used in this case include house ownership, types of roofing, wall material, floor materials and the number of rooms including semi-detached houses in the homestead.

Data analysis

Measurement of happiness as a proxy measure of subjective well-being

A composite index scale was used to measure happiness as a subjective measure of well-being. The Oxford Happiness Questionnaire (Hills and Argyle, 2002) had 29 statements. Generally, a score below 43 represented lack of happiness, 43 to 60 represented moderate happiness, and above 60 represented full happiness. In addition, data normalisation was done using the formula given in (i) below for the purposes of classification to avoid variables with the largest scale dominating the results (Ebert and Welsch, 2004).

$z_i = \frac{x_{i-Min(x)}}{\max(x) - \min(x)}$ Where $x = x_{ij} \cdots, x_n$ and z_i is the i^{th} normalised data... (i)

After normalisation of data, the happiness index was re-categorised as follows; below 0.43 represents lack of happiness, between 0.43 to 0.60 moderate happiness, and above 0.60 full of happiness. Also, the normalisation formula was used in computing indices for asset ownership and the condition of the household dwelling. Thus, the responses were clustered into three categories to get rid of any confusion that may arise from having several responses. According to Ebert and Welsch (2004), the objective of data normalisation is to identify the most suitable procedures of handling the problem at hand taking into account their properties with respect to the measurement units which the indicators are expressing and their robustness against possible outliers. The reliability analysis test for degree of happiness was measured using Croubach's alpha. However, the alpha values were interpreted according to George and Mallery (2003) as follows, >0.9 excellent, >0.8 good, >0.7 acceptable, >0.6 questionable, > 0.5 poor and <0.5 unacceptable. The scale reliability coefficient for degree of happiness in this paper was 0.716 which was acceptable.

Computation of household asset index

However, based on the conditions of the dwelling of the household, households were categorised as good, moderate, and poor. The calculation formula (ii) used in valuing the domestic asset is given as

$\sum_{h=1}^{H} [\sum_{k=1}^{k} (w_h + a)$ ……………………………………………………………… (ii)

Where H is the number of assets owned by the household, w_h is the weight of the asset h, a is the age adjusted to weight, K is the number of assets h owned by the household (Johnson *et al*., 2013). Livestock assets were further computed using Tropical Livestock Units (TLU/ha) which for cattle, goats/sheep, and poultry were 0.7, 0.1 and 0.01, respectively (FAOSTAT, 2015). The first measure of material wealth focuses on multispecies livestock holding represented in Tropical Livestock Units weight equivalent (Seiff, 1999).

Analysis of quantitative data

Descriptive and inferential statistical analyses were used for the analysis of quantitative data. Independent t-test was used to determine whether there were significant differences (p<0.005) in farmers-pastoralists opinions on personal security, happiness, asset ownership, condition of the household dwelling and education as a result of resource use conflicts. However, the factors influencing happiness were determined using the ordered logistic regression model. According to literature (e.g. Boes and Winkelmann, 2006; Haghjou *et al.*, 2013), an ordered logistic regression analysis is applied when the response variable has more than two categories with a natural order or rank. The model was preferred because the dependent variable happiness was presented in terms of graded scale. Happiness scores were normalised to vary from 0 to 1using (observed value-min value)/ (max value-min value) formula as shown in equation (i).

The ordered logistic model (iv) was specified as follows: the categories of happiness were defined based on the assumption that there was a set of j indicators of happiness. When j = 0 no household is happy. Happiness is dependent on the following factors: actual age, sex, wealth, education and so on.

It was assumed that an ordered logistic regression model is adequate to define the probability of a household being happy if j = 0

$$p[y_1 = j / x_i] = \frac{e^{\beta_1 x_i}}{1 + \sum_{k=i}^{j} \ell^{\beta_k x_i}} + \varepsilon_{ij} \text{ ....(iii)}$$

Whereby

$p(y)$ =The probability of success,

ℓ = the natural log,

α = the intercept of the equation and

ε_{ij} = the Random error for happiness i.

$\beta_1 to\, \beta_k$ = coefficients of the predictor variable,

$x_1 to\, x_k$ = the predictor variables entered in the ordered logistic regression model.

In this study, the probability of a household being in the highest category of happiness in the conflict affected area was computed. The independent variables comprised: x_1 = Age of the household head in complete years, x_2 = Sex: 1 = Male and 0 = Female), x_3 = Household size: (the actual number of people living in the household), x_4 = (Ethnicity: 1=Maasai and 0= Non-Maasai), x_5 = (District: 1=Kilosa and 0= Kiteto) x_6 = Education: the number of years spent in school, x_7 = Normalised household asset index x_8 = Condition of the household dwelling: Poor housing=1, Moderate housing = 2, Good housing = 3)]. The Maasai ethnic group was also singled out over other pastoralists groups because they are the most dominant ethnic group keeping livestock and therefore they are the leading group for being in constant conflicts with farmers in the study area. Other pastoralists and agro-pastoralist groups particularly in Kilosa include Barabaig and Sukuma (Tanga, 2008).

Results and discussion

Threats of resource use conflicts to the personal security well-being of farmers and pastoralists

Personal security threats due to resource use conflicts were identified in the study areas, these included: loss of life; this was reported by 19.0 % of the respondents suggesting that there was low rate of violent conflicts; Loss of property; this was reported by about two thirds (63 %) of the respondents showing that household suffered a substantial loss of household assets due to conflicts; farmers suffered more physical pains or assaults (40.4 %) compared to pastoralists who suffered less (4 %), apparently indicating that pastoralists were the ones causing troubles to farmers the most. Finally, post-traumatic stress was higher among farmers, while the fear of being attacked was almost at the same level among farmers and pastoralists as shown in Table 1.

Table 1. Personal security threats due resource use conflict between farmers and pastoralists

Threat to personal security (n=373)	**Responses** Farmers (%) n=230	Pastoralists (%)n=143	Overall (%) *n=373*	**Rating mean score** Famers $\bar{x}$	Pastoralists $\bar{x}$	t-values ($p<0.05$)	P values
Post-traumatic stress	196(85.3)	116(80.9)	308(83.0)	1.1913	1.2098	0.274	0.816
Fear of being attacked	214(93.0)	133(93.1)	346(93.0)	1.5957	1.6643	1.330	0.181
Loss of property	40(17.4)	102(71.3)	234(63.0)	1.4261	1.2867	2.783	0.006*
Loss of life	56(24.3)	16(11.2)	72(19.0)	1.7565	1.8881	3.393	0.001*
Physical pains	138(40.4)	6(4.0)	141(38.0)	1.0696	1.0769	0.263	0.793

NB: Numbers in brackets indicate percentage while those outside the brackets indicate frequencies; *Significant at $p < 0.05$, two-tailed independent t-test

Studies in sub-Saharan Africa suggest that depression and posttraumatic stress disorders (PTSD) (Oyok and Akello, 2011), loss of close relatives, suffering, beating, and loss of property mainly livestock, which occurs during looting (Turyahabwa *et al*., 2011) are common aftermaths of resource use conflict in the affected areas. This suggests that the psychological effects caused by these conflicts might even be worse than the physical injuries. This is because of high rate of fear of being attacked and post-traumatic stress reported by farmers and pastoralists. This situation is manifested through reduced morale among the respondents of engaging in farming activities for fear of being attacked, thus, affecting their well-being. The observation was supported by observation during focus group discussions whereby farmers pointed out that they were living in constant fear of their crop being destroyed by livestock and being beaten by the *"Korianga's* as they tried to resist the attacks. Korianga is presently powerful age-group among the Maasai ethnic group vested with all the rights and privileges of protecting the society and their cattle against the enemies. Therefore, the group acts as the militia among the Maasai community. Similarly, FGDs with pastoralists revealed that, persistent conflicts had always kept the young men on the alert, to strategically keep watch during the day and at night against any attempt directed towards their cattle or community members. Similarly, among the farmers the presence of a militia groups known as "*ujaki"* and "*sungusungu"* in Mbigiri village was referred to during interviews and FGDs. The role of the militia groups was to protect their communities against attackers by providing the required security. The presence of militia groups within the crop cultivation and pastoral communities does not auger well with the personal security and well-being of the farmers and pastoralists. According to Ero (2000), as much as these militia groups were mobilized to defend their communities against violence, they also perpetuated much of the violence and armed internal conflicts, causing massive loss of life and widespread damage.

The results of an independent t-test (Table 1) show that personal security threats as a result of resource use conflicts were more or less the same between farmers and pastoralists. The results showed further that households' personal security, which entailed loss of property (t=2.78) and loss of life (t=3.39), differed significantly (p<0.05) in their mean rating scores between the two groups.. These results suggest that farmers and pastoralists had similar opinions on the threat to personal security caused by resource use conflicts. Nonetheless, compared to farmers, loss of property among pastoralists ($\bar{x}$=1.426) was the most significant personal security threat than loss of life ($\bar{x}$=1.888). The above finding suggests that loss of life and property due to conflicts were the most threatening security issues which are related to the well-being of farmers and pastoralists in the study area. These study findings are similar to those reported in Nigeria by Adisa (2011) who showed that manifestations of the conflicts ranged from mere disputes to violent clashes resulting in loss of livestock, crops, life and valuable property. Interestingly, post-traumatic stress, fear of being attacked as well as physical pains were not significant among the two groups. These results suggest that there were few physical confrontations between the farmers and pastoralists during the conflicts. These findings show further that the parties in conflicts continued with their production activities without having the fear of being attacked.

Threats of resource use conflicts to the psychological well-being of farmers and pastoralists

Table 2 shows the psychological effects of conflicts between farmers and pastoralists in the study area. An independent samples t-test result showed that losses as a result of resource use conflicts were more felt among the farmers than among the pastoralists. The results in Table 2 show that rating mean scores of the effects of conflicts with respect to the quality of life among households between pastoralists and farmers differed significantly (p < 0.05). The areas with differences include anger/anxiety/emotional exhaustion (t = 4.49), staying away from home (t = 3.87), marital dissatisfaction (t = 3.40), farm abandonment/migration (t = 2.68), and sleepless nights (t = 2.21). The above findings suggest that both farmers and pastoralists had similar opinions on the effects of resource use conflicts. On the other hand, , anger/emotional exhaustion ($\bar{x}$ = 1.65), leaving away from homes ($\bar{x}$ = 1.35), abandoning farms/migration ($\bar{x}$ = 1.21), and sleepless nights ($\bar{x}$ = 1.14) were the most significant effects of conflict among farmers.

Table 2. Threats of conflicts to psychological well-being of farmers and pastoralists

	Rating mean scores			
Psychological effect	Farmer (n = 230) $\bar{x}$	Pastoralists (n = 143) $\bar{x}$	t-value (p < 0.05)	p-values
Anger/anxiety/ emotional exhaustion	1.1652	1.0350	4.494***	0.000
Frequently staying away from home	1.3478	1.1748	3.862***	0.000
Marital dissatisfaction	1.5348	1.7063	3.398***	0.001
Farm abandonment/migration	1.2130	1.1119	2.673*	0.080
Sleepless nights	1.1391	1.0699	2.209**	0.028
Declining quality of children education	1.2565	1.1608	2.177**	0.024
Reduced interest on family matters	1.2957	1.1888	1.757	0.008
Physical exhaustion	1.1174	1.0839	1.062	0.289
Complaints at home	1.2870	1.2448	0.901	0.368
Reduction of food quality and quantity	1.1652	1.1538	0.292	0.771

*Significant at p < 0.05; ** Significant at p =0.001; *** Significant at p =0.01 two-tailed independent t-test

On the other hand, pastoralists differed from farmers on their rating mean scores indicating that marital dissatisfaction ($\bar{x}$=1.71) was the leading effect of resource use conflicts. The findings are in line with those reported by Adisa (2011) showing that respondents in Nigeria agreed with the statement that, the quality of education of their children had been badly affected by the economic losses they suffered as a result of resource use conflicts between farmers and pastoralists. During the interview, one of the pastoralists in Kimana village, Kiteto said:

> "*How shall we enjoy staying with our wives in a place where fighting has become the order of the day? Our attention is currently focused on defending our cattle; when we lose them, all these wives and children will run away from us*".

It is also interesting to note that the declining of the quality of children's education, reduction of the quantity and quality of food, and reduction of the interest in the family matters were not significant among the two groups. The above findings suggest that communities in the areas which are affected by conflicts were unaware about the effects of resource use conflicts on the education of their children. These findings are different from the findings reported by Gakuria (2013) who revealed that the effects of resource use conflicts at household level include reduced access to food, interruption of children's schooling and forced migration among families. Moreover, the findings in Table 2 show that parties in conflicts, farmers ($\bar{x}$ = 1.28) and pastoralist ($\bar{x}$ = 1.25), show that an increase of complaints at the household is a major effect of resource use conflicts. In Kiteto, the complaints was to do with convincing one's spouse to return back to their home region as a means of avoiding conflict ridden areas. These results show that the ongoing conflicts severely interfered with family unity at the household level. However, these effects are location specific. These observations confirm the findings by Adam *et al* (2015) who reported that a decline in the quality of children's education and the reduction of food production were the leading effects of resource use conflicts between farmers and pastoralists. The current study suggests that the higher scores observed on anger/anxiety/emotional exhaustion, sleepless nights, marital dissatisfaction, and staying away from home (Table 2) for both farmers and pastoralists are caused by the frequent conflicts between the two groups. Constant fear and staying away from home for long periods of time helped in avoiding further attacks and injuries caused by persistent conflicts. This is method was common among households that preferred to keep away from direct confrontations. Also, the higher scores on farm abandonment might have serious repercussions on agricultural production, food security, overall sustainable development as well as household well-being among farmers and pastoralists in the study areas.

Normalised household assets, dwelling condition and happiness indices for farmers and pastoralists

In view of normalised household asset index, results in Table 3 show that the majority (77.5 %) of the households in the study areas were poor while only 13.4 % of the households were non-poor. However, the very poor households were below 10 % (Table 3). On the basis on wealth index, there were fewer non-poor among pastoralists than were the farmers. This suggests that the value of livestock, which is the single most important asset owned by pastoralists, was higher than was the value of household assets owned by farmers. According to Østby *et al.* (2009), the onset of conflicts in sub-Saharan, where deprivation regarding household assets is relatively strong, is most likely to lead to strong integrated inequalities, and further deprivation.

The mean and standard deviations were used to normalise data in order to determine the condition of the household's dwelling. However, as an indicator of well-being, households dwelling conditions were classified into good, moderate and poor housing quality as shown in Table 3. Accordingly, conditions of the housing index indicate that 80.4 % of farmers had relatively good and moderate housing quality as opposed to only 41.3 % of pastoralists on similar categories. . The majority of pastoralists fell below average housing quality; thus, their housings were categorised as poor. These results were not surprising as most pastoralists have a tendency of building temporary housing structures as a result of mobility, (Toth, 2014; Bassi, 2017) which is the main feature of pastoralism.

Table 3. Normalised household assets, dwelling condition and happiness indices for farmers and pastoralists

		Frequency (%)		
Household asset index	**Wealth category**	Farmers	Pastoralists	Overall
Below 0.034	Very poor	24(10.4)	10(7.0)	34(9.1)
Between 0.034-0.214	Poor	182(79.1)	107(74.8)	289(77.5)
Above 0.214	Non-poor	24(10.4)	26(18.2)	50(13.4)
Household condition index	**Housing attribute**			
Above 0.742	Good	47(20.4)	15(10.5)	68(16.6)
Between 0.156-0.742	Moderate	138(60.0)	44(30.8)	182(48.8)
Below 0.156	Poor	45(19.6)	84(58.7)	129(34.6)
Happiness index	**Happiness status**			
Below 0.43	Lack of happiness	23(10.0)	32(22.4)	55(14.7)
Between 0.43-0.60	Moderate happiness	184(80.0)	89(67.1)	280(75.1)
Above 0. 60	Very happy	23(10.0)	15(10.5)	38(10.2)

Key; ***Mean index=0.124, Median=0.100, Mode=0.025, Standard Deviation=0.090, Maximum=0.627, Minimum=0.000; ** Mean index 0.4489; median; mode; SD 0.29306; minimum 0.0; maximum 1.0
; *** Numbers in brackets are percentages

Summary data on happiness among farmers and pastoralists are presented in Table 3. Also comparisons of happiness scores between farmers and pastoralists are presented in Table 5. Although the number of observations was different between the two groups, the results show that on average pastoralists seemed to be less happy than farmers. Similarly, the respondents who declared themselves as moderately happy or very happy were 90.0 % and 77.6 % among farmers and pastoralists, respectively. It is interesting to note that the percentage of the respondents who declared themselves as very happy was slightly higher among the pastoral group (10.5 %) than among the farmers (10.0 %). These results suggest that farmers were more dissatisfied with the on-going conflicts making them less happy.

The level of education of household heads in terms of the number of years spent in school was also used to determine the well-being of farmers and pastoralists in the study areas. Generally, the results showed that about 40.0 % of the household heads had not attained formal education. Pastoralists were the majority among those with no formal education (Table 4). This result suggests that even without conflicts, pastoralists do not like to take their children to school. Notwithstanding the prevailing conflicts, the issue of schooling among pastoralists seems to be more cultural based than was the case with the results of the influence of conflicts. This aspect is evidenced by earlier studies which reported that the relationship between pastoralism and education was widely acknowledged to be problematic (Tahir, 1991; Kratli, 2000). This made some analysts (e.g. Alkali, 1991) to assume that pastoral practices are inconsistent with the schooling system which requires people to stay at the same place for longer periods of time to acquire education. Low level of education among the inhabitants in the pastoral areas is escalated by lack of schools. For example, there were no schools at Emboley Murtangos in Kiteto District which is considered as a hotspot of conflicts. The majority of respondents who had completed primary education were farmers. However, this falls below the national average. According to Human Development Indicators (2016), Tanzania's expected years of schooling are 8.9 suggesting that conflicts have severely affected individuals' education in the study area. It is also interesting to note there were more pastoralists than was the case with farmers who had education above primary school level. In addition, UNICEF and UNESCO (2015) reported that one-half of the world's out-of-school children live in conflict ridden areas. These results are not surprising because resource use conflicts in both Kilosa and Kiteto have existed for a relatively long period of time; that is, over 15 years thus interfering with education of farmers and pastoralists.

Table 4. Household number of years spent in school

Years spent in school	**Number of years spent in school**					
	0	**2**	**7**	**11**	**12**	**13**
Pastoralists (%)	84(58.7)	10(7.0)	35(24.5)	6(4.2)	5(3.5)	3(2.1)
Farmers (%)	61(26.6)	5(2.2)	151(65.9)	11(4.8)	0(0.0)	1(0.4)
Overall	145(39.0)	15 (4.0)	186(50.0)	17(4.6)	5(1.3)	4(1.1)

NB: Numbers outside the bracket are frequencies and number inside bracket (%)

Comparison of well-being between farmers and pastoralists

An independent- samples t-test was conducted to compare the well-being of farmers and pastoralists in the conflict ridden areas. This comparison was based on four measures of well-being namely, the number of years spent in school, household asset ownership, housing condition, and the degree of happiness (Table 5). The results show that there was a significant difference, at 0.1 % level between farmers and pastoralists in the household's asset ownership. On asset ownership, pastoralists were wealthier than were the farmers; and this may have been due to the possession of livestock among the pastoralists. Livestock had higher value compared to other assets which were mostly owned by farmers. Table 5 shows further that there was a significant difference at 0.1% level on the housing conditions between farmers and pastoralists

Table 5. Mean SD and t value of household well-being for farmers and pastoralists

Variables	Group mean		t-value	*p*-value
	Farmers (n=230)	Pastoralists (n=143)		
Number of years spent in school	5.252(3.392)	0.131(0.013)	-5.691	0.000**
Normalized household asset index	0.020(0.013)	0.036(0.012)	3.236	0.001**
Housing condition index	0.542(0.284)	0.319(0.013)	-8.235	0.000**
Happiness Household Index	0.538(0.538)	0.528(0.086)	-2.587	0.011*

NB: Numbers in bracket are the standard deviations, **Significance levels at 1 % and *significance levels at 5 %

These results suggest that farmers were wealthier than pastoralists on housing conditions implying that conflicts decreased (t=-8.235) the well-being among pastoralists. The results show further that there was a significant difference, at 0.05 % in the degree of happiness between farmers and pastoralists. This means that farmers were relatively happier than pastoralists suggesting that conflicts impacted negatively on the well-being of pastoralists. The results show further that there was a significant difference, at 0.1 % in household number of years spent in school between farmers and pastoralists. This means that farmers were relatively more educated than pastoralists suggesting that inadequate education could have significant negative contribution to conflicts and well-being among farmers.

Factors influencing happiness among farmers and pastoralists in Kilosa and Kiteto Districts

An ordered logistic regression model show that the likelihood ratio chi-square was 250.35 and p-value was 0.029, which indicates that the model was statistically significant compared to models with no predictors. According to Louviere *et al.* (2000), a model with an R^2 of 0.495 and above is considered as an excellent fit. Since proportional odds were assumed, a single coefficient was estimated for each predictor. The dependent variable of 'happiness' was regressed on the 8 covariates shown in Table 6. The results show that district, sex, education, and condition of the household dwelling significantly ($p < 0.005$) influenced a household's degree of happiness. The rest of the predictors particularly age, household size, ethnicity, and asset ownership had no significant influence. These results are inconsistent with the findings in study by Dedehauanou *et al.* (2013) in Senegal who reported that household demographic characteristics, land and livestock assets, and housing indicators affect the degree of happiness of an individual. The reason for this difference is that ethnicity in Tanzania, unlike in other Africa's countries, is not considered when it comes to sharing of natural resources such as land. However, the author did not link the variables mentioned foregoing discussion to resource use conflicts.

Table 6. Factors influencing household degree of happiness in Kiteto and Kilosa

Variables	**Coef.**	**z**	**P>z**	**[95% Conf. Interval]**	
District of domicile	0.593	2.190	0.029*	0.061	1.124
Age of household head	-0.014	-1.330	0.184	-0.034	0.007
Household size	-0.002	-0.050	0.962	-0.078	0.074
Sex of the household head	-1.113	-3.460	0.001**	-1.743	-0.483
Education of the household	-0.915	-7.460	0.000*	-1.156	-0.675
Ethnicity of the household head	0.465	1.640	0.100	-0.089	1.020
Household asset ownership	0.375	0.140	0.891	-5.015	5.766
Condition of Household dwelling	-0.389	-2.430	0.015*	-0.703	-0.076
/cut1	-3.011			-5.143	-0.880
/cut2	1.344			-0.762	3.450

Number of obs=370: Wald $Chi^2(8) = 66.50$: Prob > $chi^2 = 0.0000$: Log likelihood = -250.34502: Pseudo R2 = 0.4953: **significant at 0.05 level: *** significant at 0.001 level

As shown in Table 6, one's district of residence highly ($p < 0.029$) influenced one’s degree of happiness. There was a positive association (Coef. 0.593) between district of domicile and household’s degree of happiness. The respondents in Kilosa were happier than their counterparts in Kiteto District. This could be attributed to the reason that there were violent conflicts in 2014/2015 in Kiteto, and which led to loss of lives and damage on property. In addition, there was mass eviction of farmers from Emboley Murtangos which might have influenced the respondents’ degree of happiness, resulting from abandonment of their farms which were crucial to their households’ well-being.

Results in Table 6 show further that there was a negative correlation (Coef. -1.113) between degree of happiness and the sex of the respondent; this was statistically significant ($p < 0.001$), implying that being a male decreased the likelihood of being in the highest degree of happiness in conflict affected areas, all the other variables in the model being constant. In other words, in the study area, female respondents were happier than their male counterparts. This observation is supported by the results from focus group discussions which revealed that during conflicts women, children, and the elderly were either left at home or hidden in the bush while the men were engaged in guarding the property and fighting back the attackers. However, these findings are different from those in a study by Jaisri (2016) who reported that there was no significant difference in the degree of happiness based on one’s sex due to conflicts. However, Jaisri reported the highest degree of happiness among young adults as opposed to the other groups of adults.

Further to the above, there was a negative association (Coef. -0.915) between education of the household head and degree of happiness, and this was statistically significant ($p < 0.000$) implying that household degree of happiness decreases with an increase in the level of education due to prevailing conflicts between farmers and pastoralists. These findings differ from those reported in a study by Chen (2012) in Asia and Botha (2014) in South Africa which indicated that more educated individuals had more extensive social networks and greater involvement in the wider world and thus they were happier. However, according to Cuñado and de Gracia (2012); Schimmel, (2009) higher levels of education do not automatically lead to greater happiness.

Condition of the household dwelling was negatively (Coef.-0.389) correlated with the respondent's degree of happiness. This was statistically significant ($p<0.05$) implying that the conditions of the household dwelling decreased the degree of happiness among households in the conflict prone resource use areas. The finding is similar with those reported in a study by Hu (2013) that showed that the status of home ownership increases one's overall happiness. In addition, Hu (2013) reported that in terms of housing satisfaction, female respondents seemed to value more ownership of a house than did males. The plausible explanation on this aspect is that households with better dwelling conditions were less happy for fear of being affected by violent conflicts as this would is likely to make them experience huge losses due to destruction of their houses. This is in contrast with their counterparts who had temporary housing structures.

Conclusion and Recommendations

Generally, based on the study finding it can be concluded that resource use conflicts affect the well-being of farmers more than they do to pastoralists in Kiteto and Kilosa Districts. It can also be concluded that there was a significant association between resource use conflicts and various dimensions of household well-being, namely, personal security, psychological aspects, condition of the household dwelling, degree of happiness and education. It is further concluded that the factors that influence degree of happiness, a subjective measure of well-being, included home district of the respondents, sex, education as well as conditions of the household dwelling. Therefore, these results not only validate research findings from other countries but also confirm the importance of education, sex, place of residence and housing dwelling conditions as important factors of happiness. Based on the study findings it is recommended that programs that provide insurance against risks due to loss of lives and property in the aftermath of conflicts should be instituted by the government. In addition, programs of improving the condition of the household dwelling of farmers and pastoralists in both Kiteto and Kilosa Districts should be provided by the Ministry of Land and Settlement Development through respective district councils. Also, the Ministry of Health should address the issues of depression and post-traumatic stress that seem to be rampant in the study areas. For instance, clinical psychologists and psychiatrics could conduct studies on depression and post-traumatic stress in the study areas and in in other conflict ridden areas to quantify the magnitude of the problems.

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Local Actors' Perceptions about Prosopis' Impacts on Ecosystem Services and Land Use: The Case of Baringo County, Kenya

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Abstract

Invasive Alien Species pose an adverse impact on ecosystem services and consequent disruption of livelihood with time. In Kenya, Prosopis, locally known as 'Mathenge' has received the most attention from development stakeholders, policy makers and environmentalists. Introduced three decades ago, their invasive impacts have currently called for urgent need for effective management. Inadequate integration of all stakeholders has however rendered management efforts unsustainable. This study sought to: assess local actors' perceptions on the causes and invasion impacts of Prosopis on ecosystem services; evaluate the factors influencing their perceptions, and assess responsive land use options adopted by local actors. The study adopted a descriptive survey employing both qualitative and quantitative methodologies in data collection and analysis. Questionnaires, interviews, case histories and focus group discussions were adopted for empirical data collection while secondary data reviewed from; books and journal articles. Purposive, cluster and random sampling methods were used in the selection of the study area (Marigat), sub-locations and households respectively. Findings showed that although purposes for Prosopis introduction have been met, it poses a net negative impact on ecosystem services and livelihoods. Demographic characteristics were statistically insignificant at predicting local actor's perceptions on net impacts of Prosopis. Despite being more vulnerable to the invasion impacts, lack of land ownership rights has limited the capacity of women to efficiently participate in management interventions. Respondents from both heavily and less invaded sub-locations condemned further geographical extension of Prosopis. However, local utilization and mechanical clearance were preferred in low and heavily invaded areas respectively. Early detection and rapid response was strongly recommended at initial establishment to curb Prosopis spread. This demonstrated the need for a context-based management strategy that would see Prosopis coverage not exceeding the current levels in less invaded sub-locations while at the same time, reduce its cover by half in the heavily invaded areas so as to foster control while enhancing its benefits to the rural poor

Introduction

Invasive Alien Species (IAS) are non-indigenous species that adversely affect habitats economically, environmentally or ecologically, where they have been introduced, either accidentally or deliberately, outside their normal distribution range (Masters and Norgrove, 2010). They are key drivers of human-caused global environmental change (Shackleton *et al*., 2014) that adversely impact on ecosystem services and consequent disruption of livelihoods. IAS are the most serious threats to UK's populations of the endemic, and often endangered, species. In South Africa, the costs inflicted by woody IAS on Ecosystem Services (ES) were estimated at USD 1 billion per year (0.3 % of South Africa's GDP), and could rise to more than 5 % of GDP if invasive plants are allowed to reach their full potential (Van Wilgen and de Lange, 2011). In Kenya there is no other invasive alien species that has received more attention from development stakeholders and policy makers than Prosopis, locally known as 'Mathenge'(Maundu, 2009).

Prosopis is a xerophytic woody weed suitable for rehabilitation of Arid and Semi-Arid Lands. The species was introduced into Kenya around three decades ago to rehabilitate the ASAL environments (Mwangi and Swallow, 2005). Despite benefits derived from Prosopis as a source of fodder, food, fuel wood, shade, desert rehabilitation and flood regulation, the adverse impacts of Prosopis based on its invasiveness, resistance and poisonous nature have called for the need for management interventions. The main adverse impacts of Prosopis highlighted by some authors (Choge *et al*., 2002; Mwangi and Swallow, 2005; Anderson, 2005) are the health impacts on humans and livestock through physical injury, obstruction of roads and water points, encroachment of pastoral and agricultural lands and a fueling factor to insecurity as Prosopis thickets forms a hiding ground for thieves. The four dominant responses to Prosopis invasion have been: 1) Prevention in areas not yet invaded, 2) control of its expansion, 3) reduction of its abundance or cover in invaded areas, and 4) adaptation to its impacts (Shackleton *et al*., 2014). In each method, the main technological interventions in managing Prosopis are mechanical removal of the tree, chemical and biological control methods. While some countries channel their efforts at control of IAS, others advocate for conservation whereby species redistribution have to be mitigated rather than simply resisted (UK Environmental Audit Committee report, 2013). The latter ideology seems more practical as invasive species are extremely difficult and costly to control and impossible to eradicate due to their life history traits which favor and enhances their survival and proliferation. This however, does not invalidate management strategies as substantial successes have been observed where diligent and consistent control measures are adopted. In South Africa, the estimated value of ES preserved through biological control in 2010 amounted to US$ 4 billion annually (De Lange and van Wilgen, 2010).

In most Kenyan ASALs, just like in India, management of Prosopis and rural economy has been simultaneously addressed through control-by-utilization (, Choge *et al*., 2012; Shackleton *et al.*, 2015). This approach is however a justification for further distribution of IAS as it creates a dependence on the resource (Choge *et al*. 2012). Depending on the benefits derived or costs incurred from Prosopis invasion, there have been divergent opinions on its management among local actors (Sackleton *et al*., 2014). While pastoralists prefer complete regular clearance of Prosopis due to their implications on livestock production, agro-pastoralists communities who generate some benefits from Prosopis prefer control through utilization (Ilukor *et al.*, 2014). According to Shackleton *et al*. (2014), divergent perception on the impacts and management of IAS is contentious to its sustainable management. While Mwangi and Swallow (2005) posits that an understanding of local perceptions may provide reliable insight into the valuation of invasive species, she further clarifies that it provides no clear relationship between such valuations and local responses to appropriate management of IAS. This might be because studies on perceptions have been limited to local actors' preferences and valuations of IAS rather than the factors influencing their perceptions. A consensus reached by previous studies (Nakano *et al.*, 2003; Mwangi, 2005; Dubow, 2011) has indicated that the management of IAS is therefore a complex problem which can best be addressed through a multi and transdisciplinary approaches, guided by empirical data integrated with theory. The domains of ecology and more recently, economics often applied by researchers in addressing invasion (Shackleton *et al*., 2015) will be more holistic and comprehensive if the social dimensions are incorporated. Local actors' perceptions on Prosopis invasion are therefore crucial in its sustainable management, as explored in this study which sought to: 1) Evaluate local actors' perceptions about the causes and invasive impacts of Prosopis on ecosystem services and livelihoods, 2) Assess responsive land use options adopted by local actors in managing impacts of Prosopis , 3) Analyze factors influencing local actors' perceptions on Prosopis invasion in Marigat Sub- County, Baringo County.

Methodology

StudyArea

Baringo County is situated in the former Rift Valley Province, and occupies an area of 11,015 km ^{2} of which 165 km ^{2} is covered by surface-water and is located between longitudes 35^0 30'' and 36^0 30" East and between latitudes 0^{0}10' South and 1^0 40'' (County Annual Development Plan, 2015/2016). It is largely an ASAL with a generally bare ground springing up with ephemeral herbs when it rains, an indication of severe ecosystem degradation. The main economic activity in these regions is pastoralism, small scale fishing and bee-keeping as well as subsistence farming and irrigation in Pekerra irrigation scheme in Marigat, Kollowa and Barwessa (Baringo County Annual Development Plan, 2015/2016). The area of focus for this study was Marigat sub-county, a fairly flat plain on the western, lowlands of Baringo County, approximately 20 km from both Lake Baringo and Bogoria. While pastoralism is the main source of livelihood, subsistence agriculture and small scale irrigation is also practiced in areas adjacent to the surface water bodies. Prosopis stands in Baringo County are mainly confined to Marigat sub-county (County Annual Development Plan, 2015/2016).

Materials and methods

The study adopted a mixed methods design integrating qualitative and quantitative research methods due to the interdisciplinary nature of the subject under investigation. While qualitative features dominated the study, quantitative approaches were employed in data analysis and interpretation. Qualitative data from FGDs, in-depth interviews, questionnaires, case histories and literature review were used to extract information on the socio-economic characteristics of local actors, evaluating their perceptions and factors informing their decisions as well as conducting explanatory studies on the relationship between responsive land use and Prosopis invasion. Quantitative methods on the other hand were confined to analysis of data and evaluation of statistical tests from where results were presented in tables and graphs. Factors influencing perceptions of local actors on Prosopis management were analyzed using logistic model which adopted equation (i) for the analysis of observation, $Y_{i,}$ as specified in table 1below.

Logistic regression model is a special form of linear regression apart from the fact that they have different assumption relating to the relationship between the dependent and independent variables. Unlike linear regression which assumes the Gaussian distribution (normal continuous probability distribution) the probability distribution in logistic model is a Bernoulli distribution where a random variable takes the value 1 with probability p and 0 with probability q=1-p. This is because the predictor variable is binary in nature, taking the values 1 for a case and 0 for a non-case. Consequently, the predicted variables are probabilities limited to 1 or 0 values through the logistic distribution. Two parametric models routinely applied in the analysis of binary responses are the logit and probit models as there are no theoretical justifications favoring one over the other. However, Manski (1989) suspects that the choice between the two is crucial when the sample is response-based. The choice of probit and logit models has therefore been appropriated to the analysis of random and fixed effects respectively (Maddala, 1987), a rationale that is justified by convenience. Maddala (1987) states that the choice between the two models is innocuous since they yield similar results. The only difference between the normal and the logistic distribution curves is that the later has a heavier tail.

Logistic function;

$Y_i = \beta_0 + \beta_1X_{1i} + \beta_2X_{2i} + \beta_3X_{3i} + \beta_4X_{4i} + \beta_5X_{5i} + \beta_6X_{6i} + \beta_7X_{7i} + \beta_8X_{8i} + \beta_9X_{9i} + X_{10} + v$…… (i)

Table 1. Logistic regression variables

Y_i	Local actors' perceptions on the net impact of Prosopis (Values of 1 for net positive impact and 0 for a net negative impact)
	Level of Prosopis invasion (Percentage Prosopis cover)
X_1	Age of respondent
X_2	Gender (1 for Female and 0 for Male) of respondent
X_4	Years lived within the study area
X_5	Highest level of formal education
X_6	Main source of income (1 for pastoralism and 0 if otherwise)
X_7	The most preference method of Prosopis management (1for control through utilization and 0 if otherwise)
X_8	Participation in Prosopis management programs (1 for respondents who have participated and 0 for those who have never participated)
X_9	Land tenure system (1 for communal land tenure system and 0 if otherwise)
X_{10}	Existence of female land ownership rights (1 for respondents who believed women possess land rights and 0 where women had no land rights)
	$\beta_{0,}$ is the intercept or the value of the independent variable when dependent variable is equal to zero
	$\beta_{1,}$ β_2 …..β_k represent a column vectors of regression coefficients indicating the relative effect of a particular explanatory variable on the outcome.
	X_1, X_2…..X_k represent a row vectors of regressor values for variable i and
	v_i represent a random error or disturbance value for observation i (Abbott, 2009)

Sampling

Purposive, cluster and random sampling methods were used in the selection of the study area (Marigat), sub-locations and households respectively. The household head and first household member formed part of the sampling units. This was to ensure that different gender perspectives were considered. However, in cases where only one member was found in a household, a single respondent was interviewed. Snowball sampling was used to identify two case histories, people considered most aged and have stayed in the study area all their lives, an indication that they had widespread knowledge on the invasion process and response in the area over time. Table 2 (below) presents the sample size and distribution per sub-location.

Table 2. Number of respondents' distribution per village

Sub-location	No.of villages	No. of respondents
Loboi	12	31
Kapkuikui	11	29
Salabani	8	21
Mesori	8	21
El Dume	8	21
Kailer	9	23
Ngambo	11	29
Sintaan	5	13
Logumgum	9	23
Sandai	15	39
Total	**96**	**250**

Source: Survey data

Results

Socio-demographic Characteristics of Respondents

There were 250 respondents interviewed, 52 % of which were male and 44 % female. The male gender constituted 80.7 % of the household heads. Majority of the respondents (52.4 %) were aged between 40 to 50 years old and had stayed in the study area for over 30 years. A significant number (29.6 %) of the respondents did not have any formal education while only 6.8 % had university degree. An overwhelming 73.2 % practiced cultivation as their main income source with only 8 % relying heavily on pastoralism as illustrated in fig 1below.

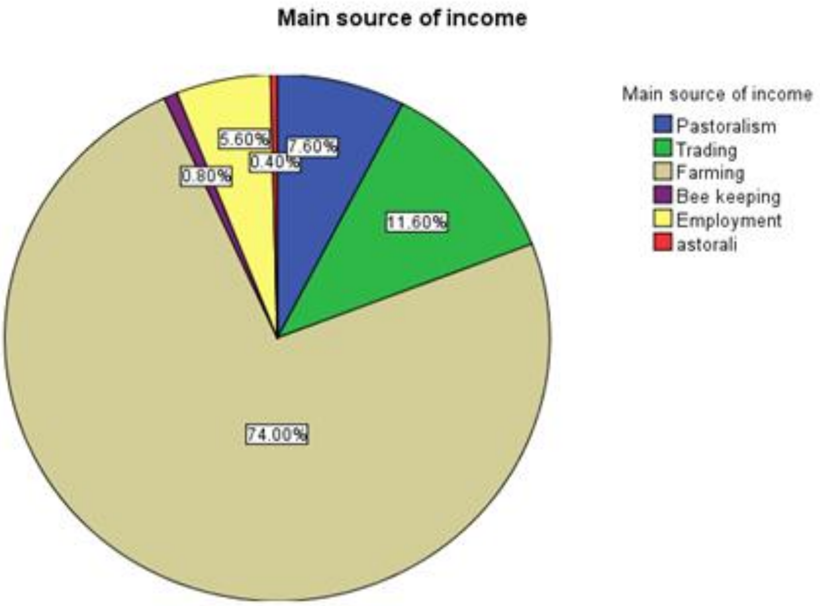

Figure 1. A bar graph showing respondents' main sources of income. Source: Survey data

Perceptions on causes of Prosopis invasion

Majority of the respondents (85.2 %) believed that Prosopis was introduced to curb desertification in Baringo and has acted as wind breakers, soil stabilizers and climate regulators (Figure 2).

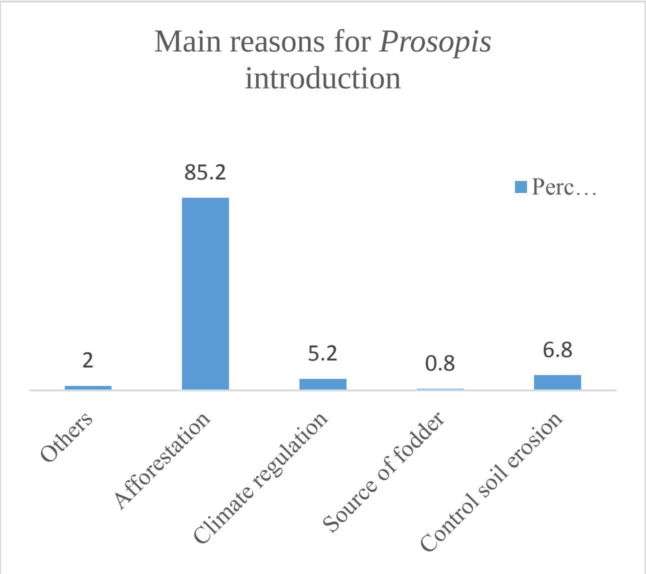

Figure 2. A graph showing reasons for Prosopis introduction.
Source: Survey data

Prosopis invasion began two decades after introduction, the process being enhanced by livestock, floods, surface run offs, wind, human beings, culture of the local community and favorable environmental conditions, in the order of their significance.

Impacts of Prosopis invasion

Prosopis poses both positive and negative impacts on ecosystem services resulting in a conflict of interest based on its net impacts to the community.

Positive impacts of Prosopis invasion

Prosopis was believed to be an integral source of fuel (98.2 %) both for domestic commercial purposes. Statistics from the Kenya Forest Service estimated a weekly charcoal production of 750 bags amounting to an estimate of KES 300,000 weekly income to the Marigat residents. This triples the amount that could be paid out to the community by Cummins power plant, a private industry specializing in power generation from Prosopis. All respondents agreed that Prosopis provides shade from the scorching sun, and consequently a cooler microclimate. An overwhelming 97.6 % believed that it improves soil fertility and controls erosion. Although rarely consumed by residents of Marigat, respondents confirmed the possibility of extracting bread flour from its pods. The pods were also consumed by goats as fodder. A small percentage (6.4 %) stated that Prosopis roots can be boiled and used to effectively cure ailments such as body rushes, stomach and headaches. This was however a controversial use of the tree which was believed by the majority (92.4 %) to be poisonous to human health.

Negative impacts Prosopis invasion

Despite the perceived benefits, detrimental impacts of Prosopis were evident. Prosopis has encroached on pastoral land, colonizing natural pastures for livestock and obstructing their watering points. Use of Prosopis pods as fodder was believed to inhibit digestion and result into tooth decay while the thorns inflicted physical injuries to livestock. Invasion of residential and farm lands, had led to loss of aesthetic and productive values of land as well as destruction of buildings through extension of their roots. Regular clearing of the tree was time and labor consuming. High clearing costs was reported to be the most severe impact on farming activities by 73.6 % of the respondents. It was also believed that where Prosopis thrives, no other native species survives as it out competes native species. Prosopis overgrows, obstructing paths and access ways to water resource. This exposes people to body injuries from their thorns. Clinical officers estimated 3 to 7 monthly reported cases being casualties of physical injuries from Prosopis thorns. An interaction with victims of Prosopis injuries confirmed that the scars transform into permanent deformations even after healing. Prosopis also produces numerous seeds and pods that are swept away by run offs into water bodies, resulting into their pollution.

Responsive land use options

Adoption of suitable land-use options was a major responsive strategy by local actors to invasion impacts. The belief that Prosopis rarely survives on a land exposed to regular disturbance, had prompted local actors to practice continuous cultivation under permanent plots all year round. Irrigation was the main agricultural water source in Marigat. Regular clearing through thinning, pruning, burning and uprooting were also popular in settlement, grasslands and farmlands. Pruning and thinning were more preferred to burning and uprooting. Despite its detrimental contribution to invasion, an overwhelming 95.2 % of the respondents preferred pastoralism as a coping strategy to invasion on pastoral land. 28.4 % of the respondents opted to sell their livestock so as to keep a stock easy to maintain. The least practiced land use option was noted to be zero grazing, which was carried out by only 0.4 % of the respondents.

Gender perspective

Both males and females had culturally defined roles. However, some roles initially perceived to be male oriented such as farming, cattle grazing and charcoal burning, were carried out by both genders. Women were perceived to be more vulnerable to invasion impacts but men played the greatest role in managing Prosopis invasion. Land ownership right was crucial in actively engaging in management practices. However, where land was under communal land ownership, women had no land ownership rights.

Overall perception about Prosopis invasion and management

An overall assessment revealed that Prosopis had a net negative impact as indicated by the majority (52 %) of the respondents. However, this perception was greatly influenced by Prosopis invasion levels as indicated in Figure 3 below. Majority of respondents in highly invaded sub-locations perceived Prosopis to be generally beneficial unlike their counterparts in less invaded areas (less than 40 % Prosopis cover).

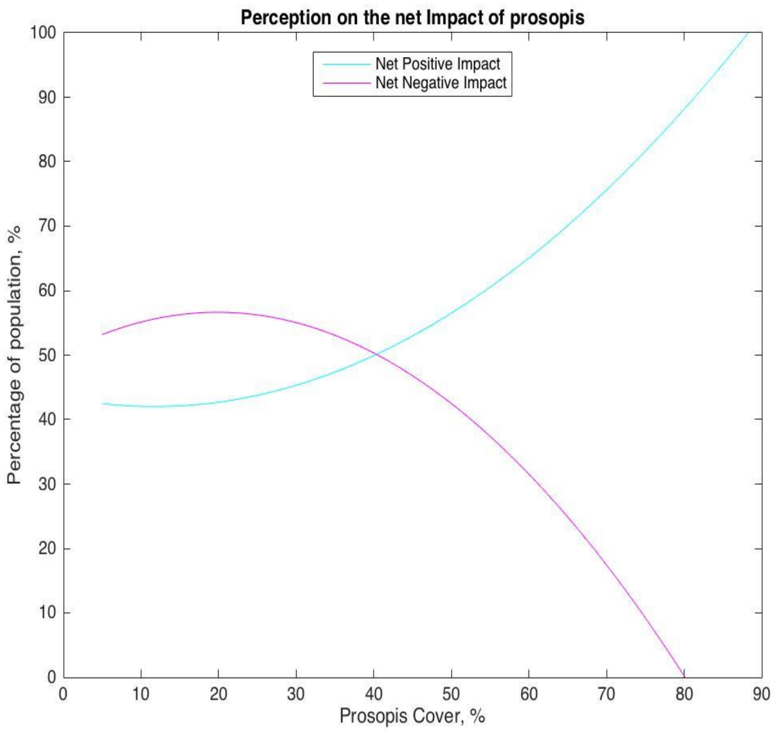

Figure 3. A graph showing local actors' perceptions on net impact based on invasion level. Source: Survey data

It was however noted that majority of respondents in all sub-locations would be comfortable with less than 50 % of the current Prosopis cover to be maintained. An overwhelming percentage (70 % and 79.3 %) of respondents from Meisori and Salabani respectively, which are among the lowly invaded sub-locations were however comfortable with the current cover. While early detection and rapid response was preferred at initial stages of invasion (Figure 4), mechanical clearance and control through utilization were perceived to be the best options in the heavily and lowly invaded sub-locations respectively as illustrated in Figure 4.

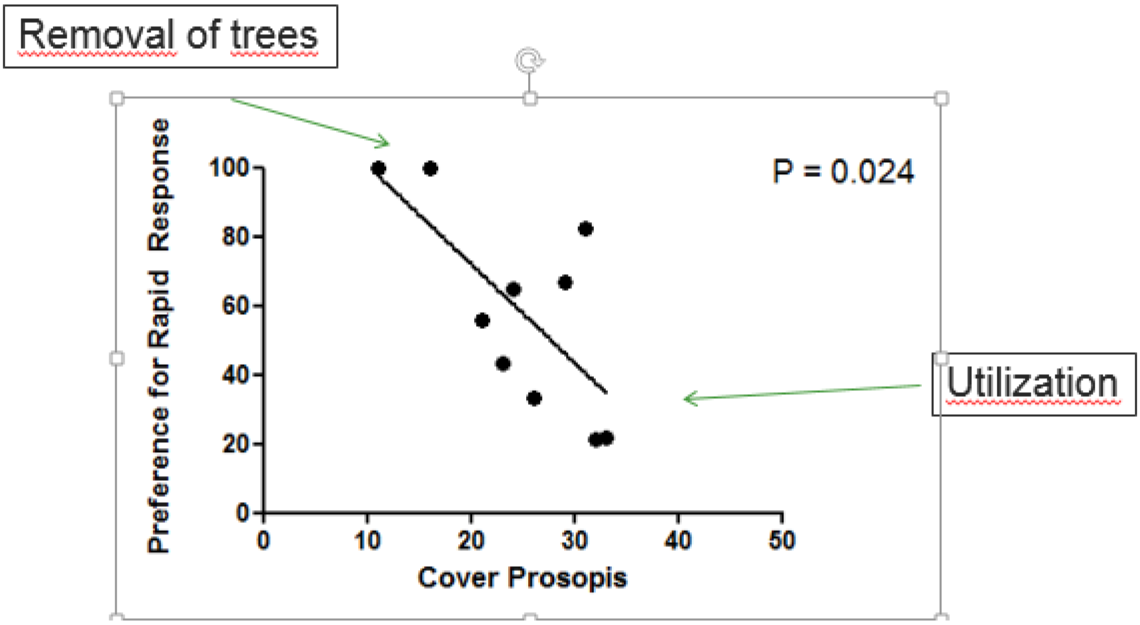

Figure 4. Early detection and rapid response. Source: Survey data

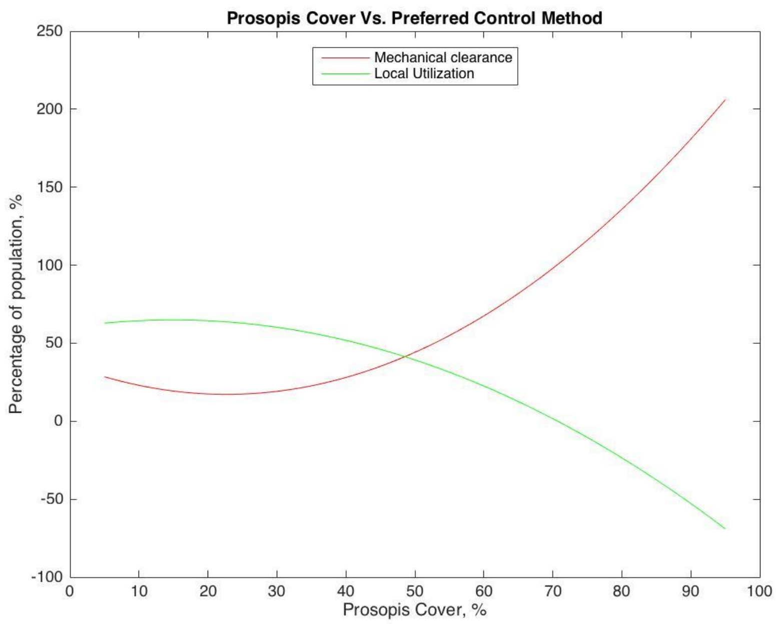

Figure 5. A Graph showing Prosopis coverage versus preferred invasion control method. Source: Survey data

Factors influencing local actors' perceptions on prosopis net impacts

Factors shaping local actors' perceptions were analyzed using the logistic model, which had an adequate fit (p>.05) for the data as demonstrated by the Hosmer and Lemeshow test results below. Variables that were statistically significant in predicting perception on Prosopis net impacts were; Prosopis cover, participation in Prosopis Management programs, preferred method of controlling Prosopis and female land ownership rights (statistically significant at 1 %, 1 %, 5 %, and 0.1 % respectively).

Table 3. Hosmer and Lemeshow test and model summary results

Step	Chi-square	df	Sig.	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	7.418	8	.492	187.068[a]	.422	.564

For every 1% increase in Prosopis cover, the likelihood of one's perception on Prosopis having a net positive impact increased by 3.5 % if all other independent variables are held at their mean. Similarly, respondents who had participated in Prosopis management programs and those who preferred control though utilization as the best management method had higher odds (odd ratios = 3.754 and 2.590 respectively) of having a positive perception on Prosopis net impact. Likewise, the existence of secured rights to land ownership and usage among women increased the odds of having a positive perception of Prosopis net impacts by 7.414.

Table 4. Factors influencing local actors' perceptions on Prosopis net impacts

	B	S.E.	Wald	df	Sig.	Exp(B)	95.0 % C.I.for EXP(B)	
							Lower	Upper
Level of Prosopis invasion (% cover)	.034	.013	7.221	1	.007**	1.035	1.009	1.061
Position in the household			1.575	2	.455			
Household head	.031	.634	.002	1	.961	1.031	.297	3.576
2nd Household member	.736	.612	1.449	1	.229	2.088	.630	6.923
Gender of respondent	.638	.561	1.292	1	.256	1.892	.630	5.685
Age of respondent	-.221	.262	.707	1	.400	.802	.480	1.341
Highest level of formal education level	-.098	.203	.232	1	.630	.907	.609	1.351
Main source of income	-.101	.794	.016	1	.899	.904	.191	4.284
Years lived in the study area	.259	.207	1.571	1	.210	1.296	.864	1.945
Participation in Prosopis management	1.323	.472	7.840	1	.005**	3.754	1.487	9.476
Preferred method of controlling invasion	.952	.414	5.286	1	.022*	2.590	1.151	5.829
Land tenure system	-.085	.583	.021	1	.883	.918	.293	2.878
Female land ownership rights	2.003	.466	18.456	1	.000***	7.414	2.972	18.492
Constant	-3.603	2.245	2.575	1	.109	.027		

Note: *, ** and *** show significance at 5 %, 1 % and 0.1 % probability levels.

Discussions

Socio-demographic characteristics of respondents

Results of this study depicted a patriarchal society, as most families were headed by males. Majority of the respondents had stayed in the study site for more than 3 decades hence their familiarity with livelihood transitions before and after Prosopis invasion. Practical experience, as opposed to formal education shaped local residents' knowledge about Prosopis impacts and management. Despite the low level of formal education among the respondents, all of them confirmed to have substantial knowledge about Prosopis and its implications on ecosystem services. Being a pastoral society, high dependence on agriculture for survival is a probable indication of adoption of alternative livelihood sources other than depending solely on their livestock, traditionally used to measure their wealth.

Reasons for introduction of Prosopis

The mean annual temperature in Baringo in the 1980s was extremely high ranging between 35^0C and 39^0C (Ngaira, 2006). The climatic condition was unfavorable for cultivation hence the community resorted to pastoralism as the only suitable livelihood option. During that time, the land was extensively bare, exposing residents to the impacts of strong winds. One respondent through a case history testified; "Daily operations were literally disrupted and visibility harbored from between 3.00 pm to 5.00 pm by dust winds. Schools and offices were closed in the afternoons due to the strong dust winds". (Personal Communication of a case history on 15th September, 2016 Kiwanja Ndege village). In a community mainly dependent on fuelwood for cooking during those times, some domestic chores such as cooking could also not be successfully carried out in the afternoons, as the strong winds could not keep the fire burning. In this light, majority of the respondents believed that Prosopis was introduced to curb desertification in Baringo, a course for which it has been successful in accomplishing.

Factors accelerating invasion

Livestock were perceived to be the main factor enhancing the spread of Prosopis by releasing scarified seeds through their dropping following their feeding on Prosopis pods, which is often indigestible by ruminants (Zimmermann, 2001). Introduction of Prosopis pods into the digestive tracks of ruminants was believed to break their dormancy, enhancing germination when later released through the animal droppings. Pastoralism, which constitutes free movement of livestock over vast pieces of land in the study area accelerates the dispersal and consequent establishment of Prosopis .It was visually evident that Prosopis cover was linearly dense along tarmacked roads and paths. The observation resonates with findings in Ethiopia by Ayuna *et al.* (2015) whose observation in 2014 identified Prosopis' spread along roads. Besides livestock following these paths in search for water and pastures, the linear pattern was associated with surface run offs besides the tarmacked roads, hence a major pathway and suitable ground for the deposition and establishment of Prosopis seeds. Ayuna *et al*. (2015) postulate that wetlands with relatively more fertile and sufficient moisture content appear favorable for the growth of Prosopis .Prosopis seeds usually cover a limited distance, mostly within the homesteads or farms during human activities such as fuelwood collection and farm land clearing. Unless dispersed further by other agents such as wind, human beings were considered to have a limited capability of enhancing invasion especially into the less invaded areas. They were rated as the least causative agent of invasion. However, Baringo residents were purported to have clung to their culture in the recent past where there was overdependence on pastoralism. Their adamancy to diversify their sources of livelihood has thus hindered their perception of Prosopis products as an integral means for survival. Michael Kanyongo, a key respondent, reported that failure to appropriately utilize this tree has therefore given it more ground to establish and spread (Personal communication on 14thSeptember, 2016 at Cummins Cogeneration Kenya Limited).

While Alves (1981) states that Prosopis is xerophytic, adapted to all types of soils, Ayuna *et al.* (2015) observed that highlands, usually dry, are less favorable for the growth of Prosopis. This position is supported by Dubow (2005), who posits that lowlands have deeper soils easily penetrated by Prosopis hence facilitating their propagation. A position shared by respondents in the study, who associate lowlands to rapid invasion. The initial bare nature and undisturbed state of land, offering limited competition during Prosopis introduction could also be an explanation for its rapid spread. This has however improved as residents diversify their sources of livelihoods through farming and charcoal burning. Despite these efforts, it is critical to note that such farming practices are only possible in the irrigation schemes leaving distant parcels of lands at the threat of invasion.

Impacts

Responses from FGDs and interviews showed that the purpose for *P. juliflora* introduction has been extremely successful. However, with the invasion of this species, it has come along with both positive and adverse impacts. It was reported that soils under Prosopis are more fertile and stable compared to where the cover was low. While results from a study, Dubow (2011) stated that soil fertility was mainly attributed to the organic matter from animal droppings and not necessarily Prosopis , it was reported in this study that being an evergreen tree, its fallen leaves provide enough forage with high content organic matter that enhances soil texture and nutrient content. Its deep and extensive roots bind the soil together, controlling soil erosion as well as trapping soil nutrients from lower soil profiles. Charcoal production business was the second main source of income to the residents of Marigat. Unlike results from Shackleton *et al.*, (2015) which stated that residents in South Africa prefer native trees to Prosopis for fuelwood, it was evident in Marigat that charcoal production is exclusively from Prosopis . This preference may however be due to the ban imposed on all other native species' utilization for charcoal production. Other benefits include source of fodder, food, shade and climate regulation and medicinal value. These benefits have been proved in other studies (Chikuni *et al.*, 2004; Mwangi and Swallow, 2005; Choge *et al.* 2012; Wise *et al.*, 2012).

Despite its positive impacts, Prosopis invasion on pastoral lands has forced the livestock herders to seek alternative sources of pastures including feeding on Prosopis pods and barks which also have adverse impacts on them. The pods were perceived to have very high sugar content, which is a good energy source for livestock. However, when acted upon by bacteria in the animals' jaws, form an acidic substance that accelerates tooth decay, consequently making it impossible for the livestock to continue grazing. Recent cases on these have been filled in court as residents seek compensation for the losses they incur on their livestock (Mwangi and Swallow, 2005). It was perceived that the pods produce a sticky substance which glues the jaws of the livestock inhibiting further chewing. A paradigm shift from overdependence on livestock to farming as the main source of livelihood in Baringo justifies the need to assess impacts of Prosopis on farming activities and grasslands. Prosopis forms a thicket limiting light penetration for other native species and grasses to survive. There was also a belief that it may be allelopathic, releasing substances, which inhibit the growth of their species, a preposition that is consistent with (Shackleton *et al.*, 2015).

Responsive land management options

It was believed that continuous cultivation ensures that land is subjected to disturbance and not left idle for the propagation of Prosopis. This land use option is however restricted to farmlands mostly confined to irrigation schemes and cannot be successfully applied to the lands not adjacent to water sources such as homesteads and grasslands, crucial for grazing purposes. Other interventions, Pruning and thinning were adopted in such areas to enhance light penetration for undergrowth, which could be useful as pasture for livestock. They also facilitate the development of few but higher quality wood from Prosopis, which are utilized as building posts and fuel wood. Burning and uprooting were the least desired invasion management methods. Dubow (2011) promoted burning based on the argument that it would prevent re-growth by denaturing the seeds. However, findings of this study indicated that burning assist in breaking the dormancy of Prosopis seeds, exposing them to a favorable environment, which enhances germination and faster spread. Uprooting, on the other hand, was considered a tedious and time-consuming option hence rarely practiced. Residents also believed that keeping a small but manageable number of cattle makes it comfortable to sufficiently provide for them hence ensuring their quality. However, this was found to be more demanding since it required them to plant grass for their livestock, a practice carried out by only 5.8% of the respondents. Those who failed to find a sustainable solution to Prosopis invasion on their livestock resorted to cultivation as a means of their livelihood.

Gender perspective on invasion management

Men were deemed stronger than their female counterparts, a factor considered to be more useful in the physical clearing of Prosopis. Their roles also entailed activities that forced them to frequently be in contact with the tree. This motivated the male gender to manage it as they also had enough time to engage in clearance of the tree. Women on the other hand were perceived to have more domestic roles which left them with little time to be involved in the management of Prosopis. The possession of land ownership rights was also considered to be a driving factor for men since they were more responsible for the management of land owned by them. Cultural requirements defined women as foreigners who migrate from their native lands through marriage, or those who will finally be married off elsewhere where they will spend the rest of their lives. This limited their access to land ownership rights. Both genders have embraced utilization as a management strategy and were equally active in the charcoal production business from Prosopis tree. A key informant however believed that utilization as a management strategy has been triggered by the benefits derived thereof as opposed to the intention of managing invasion. This position is supported by Shackleton *et al*. (2014) who posits that control through utilization is motivated around local development thereby accelerating the problem of dependence (Choge *et al.*, 2012) on the tree.

Perception determinants on Prosopis impacts

Perception on net impact and consequently, management interventions heavily depend on benefits derived or costs incurred (Sackleton *et al*., 2014). Studies by Wise *et al*. (2012) and Pasiecznik *et al*. (2001) illustrated that negative consequences of Prosopis became more apparent with increasing invasion levels thereby enhancing negative perceptions of the plant. However, benefits from IAS increases with their usage, as people tend to use IAS simply because they are available, and failure to utilize them would be equated to foregoing an opportunity (Shackleton *et al*., 2004). According to Shackleton *et al*., (2014), difficulty in penetration of Prosopis thickets by people and livestock is the main factor enhancing a negative perception on Prosopis in heavily invaded areas. An increase in the invasion level in this study may have therefore made the resource more available for residents to realize benefits from it hence simulating their positive view on Prosopis impacts. This preposition could also be a possible explanation for the positive correlation between preference for control through utilization which is prominent in Baringo (Choge *et al*., 2005) and perception for net positive impact. This is more so because the focus of management interventions is often to mitigate adverse impacts and realize a net positive impact (Shackleton *et al*., 2014). Benefits derived from utilizing Prosopis could have therefore informed this perception. According to Shackleton *et al.* (2014) overall knowledge on Prosopis invasions is vital in highlighting the need for management. Findings of this work showed that knowledge on invasion based on previous involvement on management interventions enhanced respondents' perceptions on the net impacts of Prosopis. Respondents with prior experience in management interventions were therefore more likely to have a positive perception on the net impact of Prosopis .This could be an indication that previous management strategies paid more attention on utilization options compared to the need to eradicate adverse impacts of Prosopis . This is supported by Choge *et al.* (2005) who believe that peoples' engagement in management approaches is driven by benefits they derive thereof. This, they report, has been a challenge in controlling IAS as it creates overdependence on the same.

Conclusion

Despite having a net negative impact, availability of Prosopis products and benefits derived from their utilization influences respondents' perceptions on its net impact. Extraction of the benefits is crucial in influencing the need and choice of management option. Since, the level of invasion influences benefits derived from Prosopis, its' integration in land use management as far as Prosopis control is concerned is integral in attaining sustainability. Likewise, gender based equity in land tenure system should be considered in all management approaches for a sustainable system to be achieved.

Acknowledgement

My advisors: Dr. UrsSchaffner, Dr. Jema Haji, Dr. Chritine Majale, Dr. Edward Bikketi and Dr. Simon are highly acknowledged. My greatest gratitude goes to the team working on the Swiss Programme for Research on Global Issues for Development (Haji Jema, Choge Simon, Bikketi Edward, Witt Arne, Kajembe George, Richard John, Alamirew Tena, Nigatu Lisanework, van Wilgen Brian and Ehrensperger Albrecht for their generous financial support and expertise guidance while conducting this research. Finally, I wish to thank the entire KEFRI Baringo team and respondents led by Dr Simon Choge who so passionately facilitated and coordinated my field data collection.

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Evaluation of Plantation Establishment and Livelihood Improvement Scheme as Method for Raising Forest Plantations in Kenya

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Abstract
Plantation establishment has incorporated communities and had changed over time from shamba system, Non Resident cultivation and presently plantation establishment and livelihood improvement scheme (PELIS). Success of PELIS varies from region to region. The case study evaluated PELIS in Mau, Eastern, Nairobi, North Rift and Central highlands conservancies. A socioeconomic survey was conducted followed by visit to the site. Total area under PELIS in Kenya was 18,932.63ha distributed in six forest conservancies. The overall seedling survival rate was 67 % with Nairobi leading with 78 % followed by Central Highlands conservancy with 74 % and North Rift with 65 %. Main cause of low survival was poor seedling quality. Most farmers (91 %) got their household food requirements from crops grown in PELIS plots and this contributed to household food security. The PELIS rules were abused by 55 % and 33 % of the respondents in Bahati and Dundori respectively. Most farmers (70 %) paid rent for the first year but this reduced to 10 % in the third year. The level of satisfaction with PELIS depended on how community members were involved, plot allocation methods and methods in place for solving conflicts. Results suggest that PELIS is suitable practice in which both the Kenya Forest Service and the farmers benefits. For the farmers, the food crop yields and financial earnings realized are sufficient to attract their participation. Therefore the PELIS qualifies to be sustained. KFS PELIS rules need some adjustment, especially on type of food crops, plot allocation, and collection of revenue.

Key words: survival, plantation, livelihood

Introduction

Kenya has a total forest area of 1,621,000 hectares out of which plantation area covers 138,251 hectares. Forest plantation provides wood for industrial and domestic use which would otherwise not be met by supply from natural forests. The main method used for establishing forest plantation was shamba system, which has over time changed to Non Resident cultivation and presently referred to as Plantation Establishment and Livelihood Improvement Scheme (PELIS). The shamba system was banned through Presidential decree in 1987 due to abuse that led to opening up of large areas and low seedling survival of planted seedlings. In addition, the number of cultivators who were staying inside the forest had increased to unsustainable levels (Kagombe and Gitonga, 2005). In 1994 the shamba system was reorganized and reintroduced in a few districts as Non Residential Cultivation (NRC) whose main difference with shamba, was that cultivators were to stay outside the forest stations. The final authority in making decisions on opening areas for NRC was given to District Development Committees (DDC) who had no technical knowledge in forest management, thus denying Forest Department (FD) the supervisory role it had before the ban. By 1999 large and unsuitable areas had been opened for cultivation while less planting took place due to political interference in plot allocation. The NRC was banned in 2003 by the Minister of Environment and Natural Resources through a cabinet directive due to cases of illegal extension into natural forests, river banks while replanting stalled. The MENR gave verbal authority for the NRC to be piloted in Dondori and Bahati in 2004 which began in 2006. The Method of plantation was recognized by Forest Act 2005 that mentioned that establishment should be through Non resident cultivation where applicable.

The progress report from Bahati and Dondori in 2008 showed that 900ha of fallow forest land had been opened for cultivation with 3600 households allocated half-acre plots under the management of the District Forest Officer (DFO) with assistance from the committees formed by cultivators. However there was widespread feeling from the stakeholders that NRC had not met expectations; with allegations of encroachment into natural forest, tilling of land contributing to soil erosion and that farmers were exploited.

The NRC was rebranded to Plantation Establishment and Livelihood Improvement Scheme (PELIS) in 2008 in order to address concerns raised on NRC and capture the spirit of the new forest legislation; Forests Act 2005. The overall objective of the PELIS programme was establishment of forest plantations and improvement of the community livelihood through sustainable collaborative management of gazetted forests. KFS developed rules and guidelines for implementation of the scheme as stipulated in section 47 (2) of the Forest Act 2005 of Kenya. KFS has opened up more forest areas for cultivation to facilitate plantation establishment in 15 districts on trial basis. By October 2010 about 5583 ha of area under PELIS was planted with trees and 43,72 ha was under PELIS but not planted.

In 2010 a study was conducted to evaluate the performance of PELIS at Dundori and Bahati forest stations as a case study in Kenya with reference to PELIS rules. The study examined the revenues and costs associated with PELIS, the impact of the system on tree survival, crop yield and financial income to the local farmers who practice it and governance of CFAs. The current study was built on the case study done in 2010 that was updated to 2013 and expanded to other areas where PELIS is practiced in Mau, Eastern and Central highlands Conservancies.

Objectives of the study were to:

1. Evaluate success of PELIS as method of forest plantation establishment
2. Investigate adherence to PELIS rules in Bahati and Dundori
3. Assess level of satisfaction in PELIS implementation

Research approach and methods

Description of study sites

Main sites for case study were Bahati and Dundori forest station. Additional data was collected in Kinale, Kamae , Gathiuru, Thogoto, and Timboroa forest stations. Dundori forest station is located to the North of Nakuru district in the eastern part of the Rift valley along the escarpments. Dundori forest covers an area of 3,609.3 hectares. The station is divided into two blocks namely Dundori and Kendurum which are further subdivided into five beats namely Wanyororo, Maculata, Centre, Kabatini and Station. Dundori forest station is situated in the southern part of Nakuru North District in Nakuru County. It lies about 20km east of Nakuru town.

Bahati forest station is located between the Great Rift Valley and the Nyandarua highlands, in Nakuru North subcounty, Nakuru county. Bahati forest station covers an area of 6,956.5 hectares. The station is divided into three blocks namely Rugongo, Loldorondo and Kendurumo. The blocks are further subdivided into six protection beats namely Kendurumu, Mumoi, Tetu, Pyrethrum Board, Kihingo and Loldorondo. The forest area comprises of high protection forest (3,377ha), plantation area (2319 Ha), bush land (220 Ha), bamboo forest area (38.0 Ha) and Grassland (100.3 Ha) totalling to 6,956 Ha. Both stations are under the Nakuru ecosystem manger. The other stations covered were Kinale, Kamae and Thogoto in Kiambu County, Gathiuru in Nyeri County and Timboroa in uasin Gishu County

Data collection and analysis

As part of the evaluation, a questionnaire was developed and administered to respondents who participated in PELIS. The targeted population were communities participating in PELIS in the targeted forest stations. At Dundori forest station four compartments were selected 9K, 9L, 7E and 5C while at Bahati 12 compartments were selected, 5B, 5H. 5V, 5G, 4B, 4D, 4 F, 4H, 3C, 3G, 3H and 1M. 172 respondents who had plots in the selected sub-compartments were randomly selected from farmers found working in the forest. The sample was chosen to ensure that all possible variability in the study population was adequately represented. All PELIS farmers in each compartment were informed to meet in a common place in their compartment to ballot. PELIS farmers who picked a "yes" were interviewed. The questionnaire was administered to the sampled respondents by trained KFS forest officers. The selected farmers were interviewed to get information on the size of their plots, food crop yields per plot, their involvement in CFA and adherence to PELIS rules. A round table meeting between the interviewers, CFA officials and KFS was held to find out the status of governance at local level using a check list.

PELIS plots for the selected farmers were assessed by systematic sampling and choosing any five lines of trees, counting the original number of tree seedlings and number of surviving tree seedlings to facilitate computation of survival percentage. Other parameters were assessed in the plots through observation, distance to nearest river bank, presence of soil erosion, quality of tree pruning and site of the plot. Sketch maps were used to locate the sample plots on the ground.

Secondary data from compartment registers, files and books, KFS business plan, KFS inventory data.

Results and discussions

Sampled household characteristics

Interviews and data capture was done from a of 186 farmers in the five forest stations distributed as follows (Kamae (40), Gathiuru (31), Thogoto (50), Bahati (34) and Timboroa (31) of which 54 % were male while and 46 % were female. Age distribution showed that 17 % of the respondents were youth of less than 36 years old, while 81 % of the respondents were married. The result shows that the majority (75 %) of household in all the station had 4-8 members of the household.

The result show that generally there was gender parity by the respondents with 58 % male and 42 % female. Although there was significant gender disparity at Timboroa (90 % male, 10% female) and at Thogoto (88 % female and 12 % male). The education level of PELIS farmers show that most of the respondent's highest education level was up to primary level (63 %) as shown in Figure1.

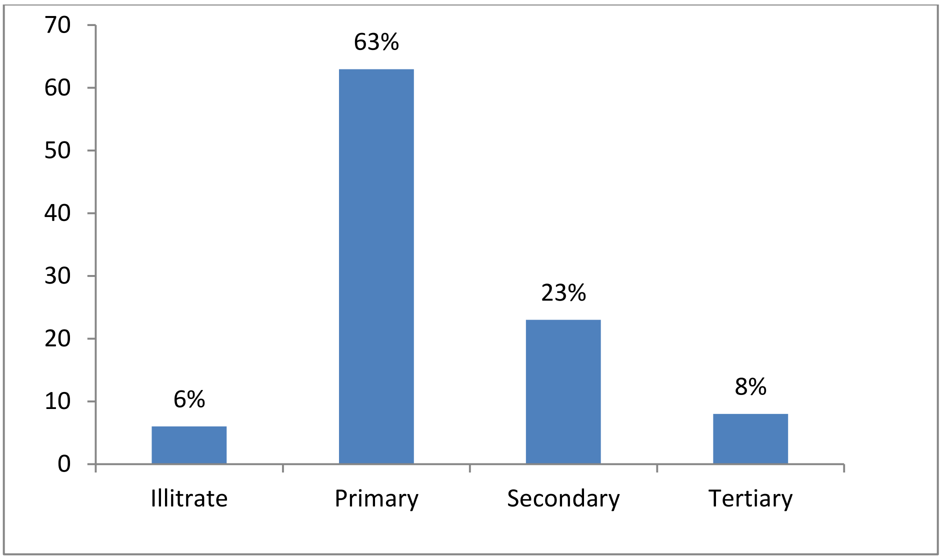

Figure 1: Level of education of PELIS farmers in the study areas

Wealth status in terms of livestock and land indicate that most respondents don't own any cattle (52 %) , 38 % own 1-3 cattle while only 10 % own more than 3 cattle as shown in figure 2. In Thogoto,88 % of the respondents do not own any cattle while 73 % of Kamae PELIS farmers own at least one cattle.

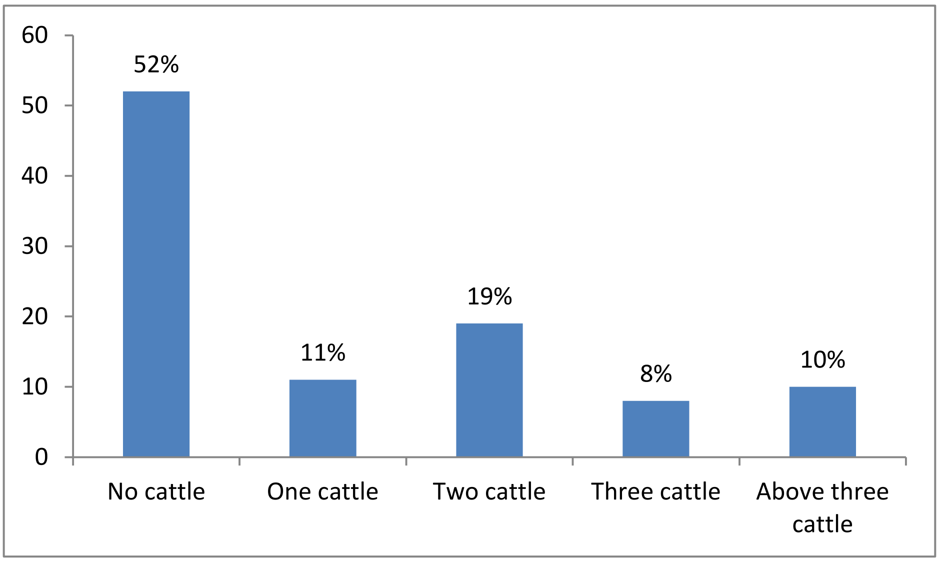

Figure 2. Number of cattle owned by PELIS farmers

Results showed that most (89 %) of PELIS farmers have no land at Thogoto forest station, with very few farmers (3 %) owning more than 3 acres of land. In other stations, PELIS farmers owned less than 3 acres of land as shown in Figure 3.

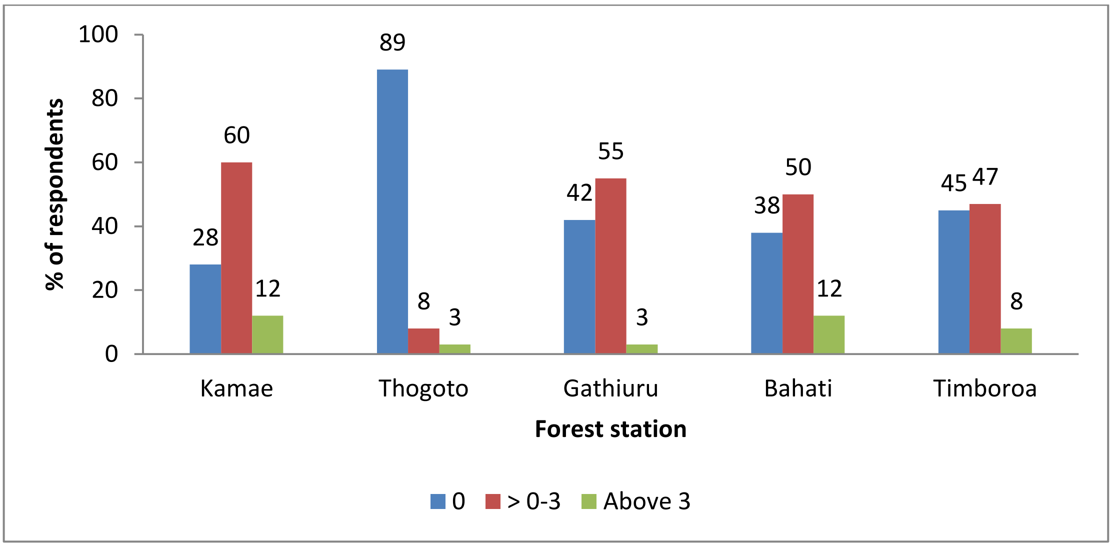

Figure 3. Land area owned by PELIS farmers in acres

Results showed that most farmers (91 %) got their food from the plots in the forest. In addition, majority (59 %) of farmers participating in PELIS were self sufficient in food for at leat 10 months in an year, 11 % for 7-9 months, 26 % for 4-6 months and 4 % for 1-3 months. Main source of income for the farmers was self employment and sale of food crops that contribiuted to 85 % of total income.

Most farmers in Thogoto and Bahati grow maize as the main crop while in Timboroa, Gathiuru and Kamae the main food crop is potatoes as shown in table 1.

Table 1: Main percentage crop type grown in each forest station

Station	Maize	Potatoes	Cabbages
Kamae	0	88	12
Thogoto	100	0	0
Gathiuru	0	100	0
Bahati	100	0	0
Timboroa	3	97	0

Areas under PELIS in Kenya

The total area under PELIS in the country was 18,932.63ha distributed in six forest conservancies as shown in table 2.

Table 2. Pelis areas in Kenya by 2013

Conservancy	County	Area (ha)	Seedling survival %
Central Highlands	Kiambu	1185.6	70
	Nyandarua	2188.98	79.2
	Nyeri	1017.6	74
		4392.18	**74.4**
Mau	Baringo	3816.2	56
	Kericho	1624.7	65
	Forest college	165	
	Nakuru	1784.9	64
		7588.4	**62.5**
Nairobi	Kajiado	126.6	78
North Rift	Elegeyo Marakwet	1291.9	
	Nandi	245.1	77
	Tranzoia	818.3	51
	Uasin Gishu	1973.35	54
		4455.25	**65**
Nyanza	Migori	75	
Western	Bungoma	1035.8	55
	Kakamega	1259.4	55
		2295.2	**55**
Overall		**18,932.63**	**66.98**

The overall seedling survival rate was in Kenya was 67% with Nairobi leading with 78% followed by Central Highlands conservancy leading with survival rate of 74% and North Rift with 65%. Tree survival is key to plantation establishment and is an important indicator of success of PELIS system.

Implementation of PELIS rules

A case study was carried out to evaluate implementation of PELIS rules at Bahati and Dundori forest stations. Results compared the set rule in the guidelines and how it was implemented in the field.

Compliance with the Forest Act.

> Rule: The permit holder must comply with the provisions of the Forests Act 2005 and any rules made thereunder. Should the permit holder or his/her agents or employees commit any breach of the Forest Act or of any rules made thereunder, he/she will have committed an offence and will render the permit liable to cancellation or any other penalty imposed by the Director through the Forests Act 2005.

The study showed that 55 % of the respondents in Bahati reported that there was abuse of the PELIS system, while 33 % of the responded reported that there was abuse of PELIS system at Dundori. Further, 42 % of the respondents at Bahati reported that those CFA members who break PELIS rules lose their plots while 30 % of the Dundori CFA members who break PELIS rules lose their plots. The finding indicates that the CFA at Bahati is stricter on adherence to PELIS rules as compared to Dundori CFA.

Eligibility for cultivation.

> Rule: All cultivators must be residents of areas adjacent to the forest stations and be members of a registered community Forest Association.

The result showed that 100 % of all the responded belonged to CFA at Bahati while 96 % of the respondent at Dundori belonged to CFA. Some of the members in Dundori had sub-leased their PELIS plots to none CFA members. This is contrary to the rules which stipulate that cultivators must be members of a registered community forest association. The study showed that all the cultivators are residents of the area adjust to the forest station with a mean distance of 3 Km between respondents PELIS plot and homestead as shown in table 3 below.

Table 3. Distance from farmers home to PELIS plot in km

Name of forest station	N	Mean	Std. Deviation	t	df	Sig. (2-tailed)
Bahati	70	3.189	2.7969	-.029	169	.977
Dundori	101	3.198	1.3804			

Demarcation of plots

Rules:

Forest zonation and mapping will be done to identify the forest areas suitable for cultivation.

The individual plots will be demarcated by the area divisional forest officers, be numbered and put on a sketch map.

The sketch maps shall be displayed on the station notice boards.

A Site-specific management plans will be compiled for each forest station implementing PELIS

Both Dundori and Bahati forest stations have functioning Forest management plans and have done zonation and mapping to identify forest areas suitable for cultivation. The study revealed that although forester Dundori had the zonation map, he utilized some of the steep areas for PELIS, allowed PELIS farmers to extend their plots to steep areas and near the river banks. The forester and divisional forest officers did not participate in plot demarcation at both Bahati and Dundori forest stations. The individual plots were demarcated by the CFA group leaders together with the forest rangers , numbered and were put on the skecth map. All the foresters did not have the skecth maps on the notice board. During our study , sketch maps were borrowed from the CFA officials for both Bahati and Dundori forest stations. Fig 4 showed that the individual plots were demarcated and most of the respondents were able to locate the plots using plot labels (59 %).

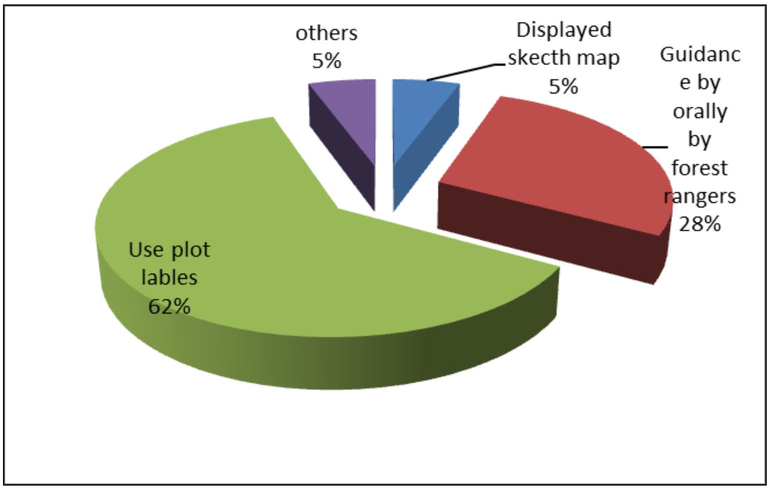

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Figure 4. Methods of location of PELIS plots in Bahati and Dundori

Plot allocation method.

Rules:

Implementation will be through user group or CFA Management Committees, consisting of representatives of cultivators.

A ballot system will be used in all cases during allocation of plots.

All Participating CFAs must sign an agreement form before cultivation commences.

All selected cultivators must obtain a permit before cultivation commences.

The two communities had CFA management committees and user group's consisting of the representative of cultivators. The Dundori CFA was called DUCOFA (Dundori community forest association while the Bahati CFA is called BACOFA (Bahati community Forest association). The results showed that 85 %, 65 % of the respondents knew the name of their CFA at Bahati and Dundori respectively. This may be due to the fact that some of the CFA members confused between the name of the group and CFA name.

Results showed that 97 % and 66 % of the respondents of Bahati and Dundori respectively reported that they used ballot system to allocate plots. The rest of the respondents reported that they were issued plots either through preferential treatment of sub-letting from mainly CFA leaders. At least Dundori plot allotment followed a different system, whereby preference was awarded to IDPs, CFA members who had worked in the KFS tree nursery for at least 14 days, CFA and group leaders' officials.

The study revealed that 44.2 % of the respondents were aware that their CFA had signed the agreement contract before commencement of cultivation while 42 % had no idea on whether the contract was signed or not as shown in Figure 5.

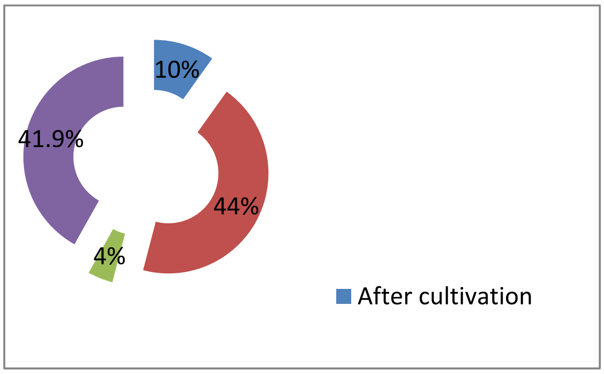

Figure 5. When agreement contract was signed

The rules states that all selected cultivators must obtain a permit before cultivation commences. The study revealed that about 70 % of the respondents obtained the permit by payment of the shamba rent before commencement of the cultivation, 20 % got the permit after commencement of cultivation while 10 % did not obtain the permit at all (Fig 6)

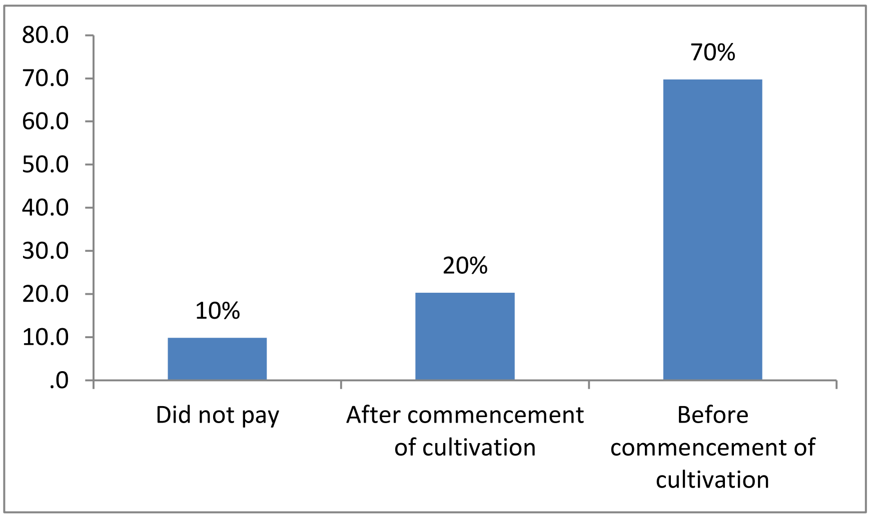

Figure 6. Time when shamba rent is paid

The study revealed that most (94 %) of PELIS farmers obtained the permit to cultivate in the forest during the first year of plot allotment as shown in fig 7 . After aquisation of the plot most of the respondents did not aquire the permit. This could be due to lack of monitoring by KFS. CFA officials were active in collection of the shamba rent in the intial stage because they also benefit as each plot winner pays Ksh 50 to be used by CFA for adminitrative issues, plot demacation and forest scout salary.

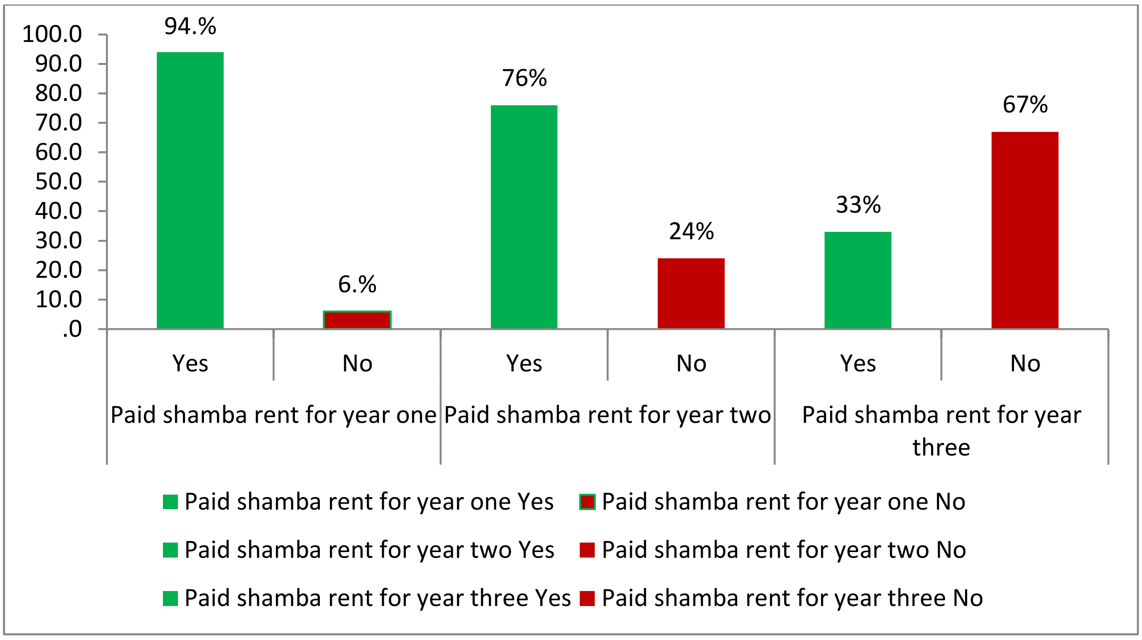

Figure 7. Comparison of payment of shamba rent

Figure 7 showed that KFS loses shamba rent as the shamba continue cultivating as the number who did not pay increased from 6 % in year one to 67 % in year three.

Crops to be grown

Rule: Only maize, beans (non-climbers), potatoes, carrots, peas, onions Dania, Chilies, Amaranthus and Cabbages shall be planted in PELIS scheme. The Service may review the crops to be grown from time to time.

All the plots visited had annual crops. Dundori forest PELIS plots had some of the unauthorized crops in the forest like snow beans and shown in the plate 1. The main crops grown were mainly maize, potatoes and beans. Other crop grown includes peas, dania, carrot and cabbages. Some farmers in Dundori had unauthorized plants on their plots such as snow bean. This is a climber plant that leads to deformed trees in the forest as shown in Plate1.

Plate 1. Snow bean in 9K at Dundori

Cultivator's obligations.

Rules:

- The user group will ensure that none of its members or agents will take any action that will be harmful to the survival of the plated trees.
- The cultivator shall ensure that he/she and/or his /her agents will not take any action that will be harmful to the survival of the planted stock. If the survival is low, they will participate in either beating up or replanting, whichever is appropriate
- Any form of interference with the normal growth of seedlings and trees is prohibited.
- The licensee and/or his agents or employees shall give assistance whenever called upon by the Service in controlling illegal activities and in preventing or fighting forest fires.
- No permit holder will be allowed to lease out or sell the allocated plot. Any attempt to lease or sell a plot will lead to the plot being repossessed and plot will revert back to the Service

Most of the respondents ensured that there was no destruction to the planted trees, but some especially at Dundori over pruned tree seedlings to allow light to their crops in 9K. Some farmers cut surviving trees in other peoples plot as shown in plate 2, 3 and 4. Some farmers had well maintained plots in terms of survival rate and shown in Plate 5.

Plate 5. Well established plantation at Dundori (9K)

The results indicate that poor survival of tree seedlings was due to bad weather during tree establishment. Respondents at Dundori reported that there was a dry period for two weeks after planting in compartments 9L, 7E and 5C in April 2010 which affected the establishment of the seedlings. Tree survival was also affected by poor planting that was partly attributed to hiring of inexperienced youth through the stimulus programme, Kazi Kwa Vijana, youth programme. The mean age of CFA respondents was 47 years while KKV employed young people of less than 35 years. CFA members were discouraged with the move as this did not benefit most of the members.

The low survival at Bahati could be as a result of poor transport of tree seedlings from the group nurseries to various sub compartments. Poor quality bare root seedlings were mainly got at Dundori with planting took place in the afternoon when those planting were tired. There was a big problem of rats and rodents especially on pine tree species in 5C. PELIS farmers used traps to reduce on the menace, which was beyond their control. Some farmers used to pull bean plant to control mole rats as shown in plate 6. Human disturbance was as a result of over pruning, cutting trees, planting wrong crops and poor weeding (Figure 8) .

Plate 6. Pull plant

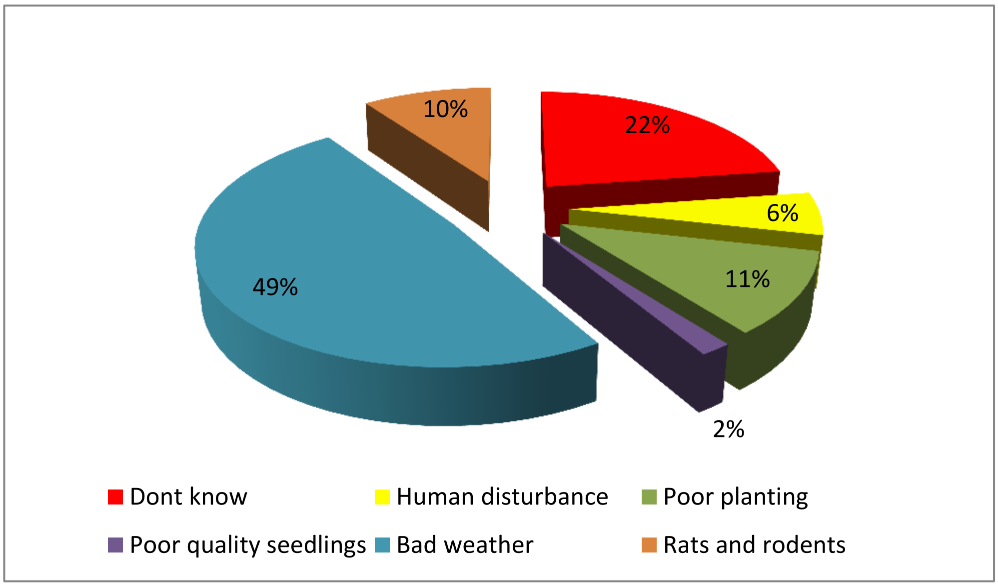

Figure 8. Main cause of low seedling survival

The results show that more than 50 % of the plots had a high tree survival rate greater than 75 % at Bahati forest station for both pine and Cyprus tree species, while at Dundori, more than 50 % of the plots for Cyprus had a high survival rate of greater than 75 % as shown in Figure 9.

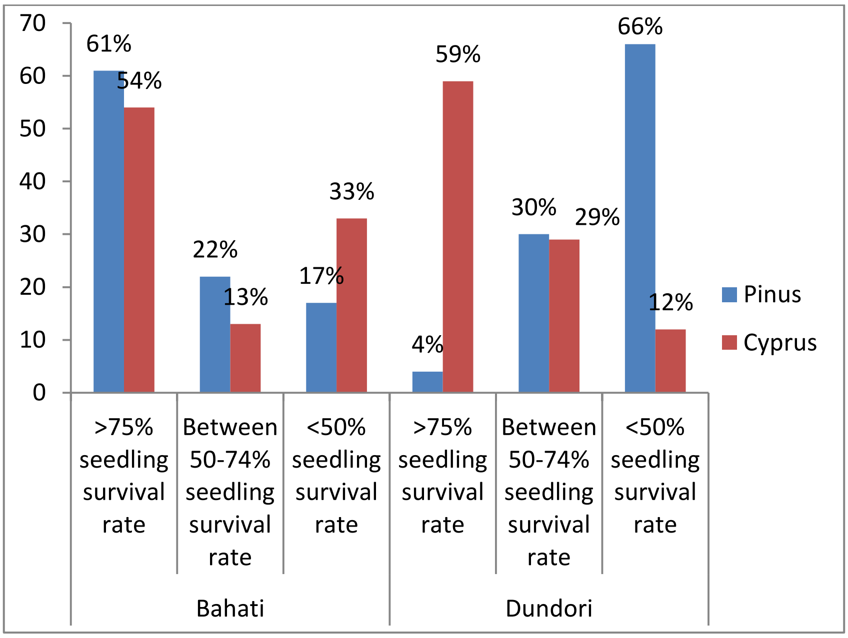

Figure 9. Categories of seedling survival rate

The low survival rate for pine tree species could be attributed to rats and rodents and poor weather condition in 2009-2010 planting seasons (fig. 10). There was no planting in 2009 due to lack of adequate rainfall

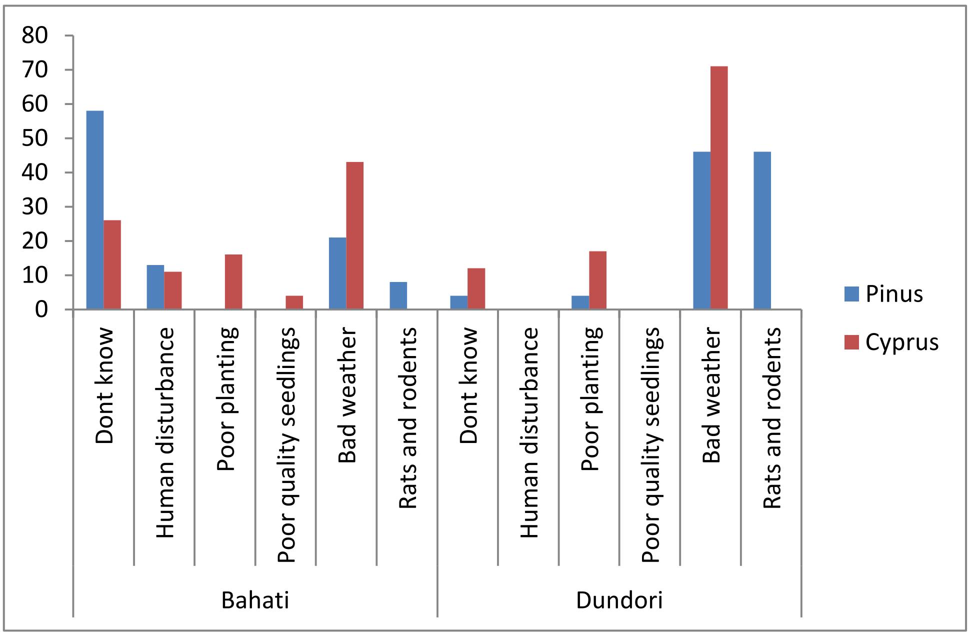

Figure 10. Main cause of low seedling survival per species

Dundori had four sub-compartments examined during the study in which there was successful seedling survival (77 %) in 9K of Cyprus tree species, low seedling survival in 7E, 9L and 5C with survival rate of 23 %, 36% and 38 % respectively probably mainly due to poor rainfall, poor planting and rats and rodents. Eleven sub-compartments were examined at Bahati forest station. There was successful seedling survival in 4D (81 %), 4H (78 %), 3G (76 %), 3H (80 %), 5H (82 %) and 1M (80 %), fair seedling survival 2C (65 %). Bahati station had low seedling survival in 5G (30 %), 5X (30 %), 5V (40 %) and 4F (33 %). The low seedling survival may be due to poor weather condition and effects of mole rats. On average the overrall tree survival rate was 70% at Bahati while it was 53 % at Dundori.

Plate 7. Cultivation in old tree plantation

Plate 8. Cultivation in mature plantion

Payment of Shamba rent

Rule:All cultivators will pay prevailing annual rental fees for the allocated plot before cultivation commences for that particular year.

The study revealed that at Dundori the forester managed to raise 40 % of the expected revenue. It was established that due to distance between KFS office and PELIS farmers homestead, CFA group leaders collected the shamba rent for on behalf of KFS. The collected revenue was handed over to the forester to issue the cultivation permit. During the first year of allotment CFA officials had incentive to collect the shamba rent due to the fact that all new allotees paid extra Kshs. 50 for administrative issues like transport to KFS office. It was not easy for the CFA officials to continue chasing plot owners to pay rent for year two to four. This may have resulted to low payment of shamba rent as shown in Table 4.

Table 4: Payment of the shamba rent

Station	Year	Years under PELIS	Area under PELIS in ha	No of PELIS plots	Rate of shamba rent	Real revenue	Expected revenue	VARIANCE	% of revenue collected
Dundori	2006	3	218	1090	165	106,000	179,850	73,850	59
	2007	4	236.9	1184	165	211,250	375,200	163,950	56
	2008	4	263.9	1319	250	19,965	592,845	572,880	3
	2009	3	275	1100	250	456,240	1,173,250	717,010	39
	2010	2	194.5	973	250	457,000	**1,144,000**	687,000	40
Total			1188.3	4576					
Bahati	2006		290.9	1455	165	54,895	240,075	185,180	23
	2007		114.09	570	165	83,105	334,125	251,020	25
	2008		232.59	1165	250		797,500		
	2009		77.13	56	250		433,750		
	2010		256	1280	250		**767,750**	0	0
Total			970.71	4526					

Size of shamba plot

The results indicate that the smallest plot (19 %) was 0.25acre, 0.5 acre (77 %) and 1acre (4 %). The small size of plots was as a result of sub-letting, change of plot numbers and layout on the ground by CFA officials to create more plots to sub-let. This mainly occurred at Dundori forest station. Area of the largest plot was 0.5 acres (66 %), 1 acre (11 %) and 10acres (2 %). The results indicate that the rule on maximum plot area was violated and could be due to the fact that some people could sublet some of their plots with some CFA officials allocated to themselves many plots.

Factors that affect the satisfaction level of PELIS in reference to the performance of KFS in implementation of PELIS.

The independent –test results in table 5 indicate that there was significant difference at 5 % probability level on the satisfaction level of PELIS between Dundori and Bahati PELIS farmers. The community at Bahati was more satisfied with PELIS as compared to the Dundori community. The results show that Bahati community with mean value of 1.68 ranked highly the involvement of local people in decision making by KFS compared to Dundori community with a mean of two. The KFS was ranked highly on allocation of PELIS plots, have mechanism of conflict resolution, able to resolve conflicts, adherence to PELIS rules, Demonstration of democracy in selection of CFA officials, by the respondents at Bahati compared to the Dundori respondents. Both communities ranked gave a low rank (3) on the interaction levels between CFA and the ecosytem manager and also between CFA and the Head of Conservancy. The community at Bahati had a low rank on the interaction between the forester and CFA while the community at Dundori ranked highly the interaction between the CFA and the forester.

Table 5. Factors that affect the satisfaction level of PELIS in reference to the performance of KFS in implementation of PELIS

	Name of forest station	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t**	**Df**	**Sig. (2-tailed)**
Rank satisfaction level with PELIS	Bahati	69	1.39	.521	.063	-2.045	168	.042
	Dundori	101	1.57	.605748	.060274			
Involve people in decision making	Bahati	69	1.68	.717	.086	-2.633	166	.009
	Dundori	99	2.00	.808	.081			
Allocation of plot	Bahati	71	1.55	.580	.069	-5.423	170	.000
	Dundori	101	2.13	.757	.075			
Site of plot	Bahati	71	1.75	.626	.074	-.746	170	.457
	Dundori	101	1.82	.669	.067			
Have mechanism of conflict resolution	Bahati	70	1.90	.764	.091	-2.739	169	.007
	Dundori	101	2.28	.960	.096			
Able to resolve conflicts	Bahati	71	1.90	.831	.099	-2.725	170	.007
	Dundori	101	2.30	1.005	.100			

Level of adherence to PELIS rules	Bahati	69	1.72	.938	.113	-3.682	168	.000
	Dundori	101	2.20	.735	.073			
Demonstration of democracy in selection of CFA officials	Bahati	70	1.93	1.094	.131	-2.766	169	.006
	Dundori	101	2.35	.877	.087			
Interaction between CFA and Zonal manager	Bahati	69	3.04	1.242	.150	-1.101	168	.272
	Dundori	101	3.27	1.341	.133			
Interaction between CFA and HOC	Bahati	68	3.26	1.241	.151	-.446	166	.656
	Dundori	100	3.36	1.432	.143			
Interaction between CFA and forester	Bahati	70	2.29	.995	.119	3.916	168	.000
	Dundori	100	1.77	.723	.072			

Discussion

The assessment of the overall seedling survival in the compartments at Bahati and Donduri show that the survival is 68 % and 53 % respectively. This is significantly different at 99% significant level. The variation in survival rate could be attributed to the fact that Bahati community had a very strong CFA that was respected by members unlike the Dundori CFA which had a high level of wrangles. All the plantations that were established in 2008 had a high survival rate (>75 %) while most of the plantations that were established in 2010 had low seedling survival rate (<50 %). The main cause of low survival rate of tree was mainly lack of rain after planting. The forester reported that after planting in 2010, there was a dry spell of two weeks. The effect of poor planting was noted during the 2010 tree establishment. The study revealed that the employment of inexperienced young community members under KKV could have contributed to low survival rate. The mean age of CFA members was 47 years while KKV minimum qualification age for employment was 35 years. The findings imply that KFS will spend more capital on tree establishment where the survival was poor. The results indicate the cost saving effect on plantation establishment can be influenced by external factors which are beyond the control of the farmer such as weather, poor quality seedlings and poor planting.

The establishment of a forest plantation is labour intensive and an expensive undertaking. Data show that to raise one hectare of cypress plantation costs more in pure wood production system than in shamba system. Although the ultimate return may justify the high initial cost in pure wood system, governments are often loath to sink very scarce capital into long term projects such as plantation which have relatively long gestation period. Therefore the need to device methods of establishing forests which do not demand heavy investment becomes imperative. The success of PELIS is dependent on adherence to guidelines and rules and how they are enforced. While the rules set out are adequate to ensure success of PELIS, enforcement by CFA and forest officers is still a main issue. The rules ensure that proper crops are planted at the right place, trees are tended to maturity and cordial working relationship between CFA and forest officers is maintained.

However, in spite of these shortcomings it is still valid to point out that the shamba system in addition to its relative efficiency and cheapness makes a substantial contribution to food production. Considering the number of peasant farmers and the yields as shown in Table 11, it is clearly evident that a substantial quantity of food is produced per year. Since most participants in the shamba systems at Bahati and Dondori lead a subsistence way of life, these food gains cannot be ignored.

The level of satisfaction with PELIS was contributed by the process and management of the system. Factors key to satisfaction were; level of involvement of community members, allocation methods, interaction with forest officers and mechanisms for solving conflicts.

Conclusions

The observations made in this study suggest that PELIS is a suitable practice from which both the Kenya Forest Service and the peasant farmers reap substantial benefits. The Forest Service benefits from reduction of forest plantation establishment costs. Furthermore, tree survival in compartments under the PELIS had vigorous growth unlike under pure wood system. This denies an allegation that intercropping young trees with food crops under the PELIS is detrimental. For the farmers, the food crop yields and financial earnings realized are sufficient to attract their participation. These benefits are in addition to the means of subsistence and social security which the shamba system provides to them. Therefore the PELIS qualifies to be sustained. KFS PELIS rules need some adjustment, especially on type of food crops, plot allocation, and collection of revenue.

Recommendations

There is need to review PELIS rules to reflect emerging issues and enhance enforcememt of regulations to improve adherence. Seedlings should be raised near to the planting areas to avoid mortality caused by damage when transporting. Improve working relationships between CFA and forest managers. Enhance monitoring systems for PELIS

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Trees on Farm Domestication Level, Opportunities and Challenges: A Case Study of *Prunus africana* in Western Kenya

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Abstract

Prunus africana is widely known for its medicinal value among other uses. The tree species has been overexploited for its bark is a highly valued remedy against prostate disorders, leading to its threat of extinction in its natural range. One way of conserving it, is through domestication. However, this is bound to face challenges within diminishing agricultural landscapes and hence the need to assess the potentials and constraints to its domestication on farm. The objective of this study was to generate information to improve strategies for its conservation and domestication in Kenya. The study was carried out on farms adjacent to Kobujoi and Kakamega forest reserves (Western Kenya) where the species naturally grow. A farm survey was conducted which was aided by use of a semi-structured questionnaire and general observation. The results indicate that farmers in Kobujoi were more aware of *P. africana* uses than those in Kakamega. Firewood recorded the highest frequency of use in both areas while its medicinal use ranked third. In Kobujoi, the species competition with the agricultural crops was the main constraint while in Kakamega, certain customs and beliefs discouraged the farmers from cultivating it ranked highest. Another major constraint cited was lack of seedlings. Its cultivation was higher in smaller farms than in larger farms. The main management practices in the two places include weeding, pruning and spot cleaning. Many farmers left the species to grow naturally, more so in Kakamega. The research findings need to be considered in species conservation strategies.

Key words: Domestication, conservation, challenges, opportunities, *Prunus africana*

Introduction

In the pre-colonial era, trees that grew in Kenya were mostly indigenous with high species diversity. Natural forests were later cleared or valuable timber species were extracted and replaced by other land uses such as agriculture, plantation forests, and human settlement among others. The introduction and promotion of agroforestry systems enhanced the use of exotic tree species at the expense of the indigenous (Albrecht, 1993). This led to a rapid decline of indigenous trees species, *Prunus africana* being one of them. *Prunus africana,* commonly known as red stinkwood, is an evergreen tree, up to 30m in height, with a stem diameter of up to 1 m, the bark is blackish-brown and rugged and branchlets are dotted with breathing spots. It has a heavy, shining foliage composed of alternate, simple leaves, oval or lance shaped, which when crushed have a bitter-almond smell. Its flowers are small, white or greenish in colour. *Prunus. africana* is a highland forest tree, growing in the humid and semi-humid highlands and humid midlands. In Kenya it naturally grows on the slopes of Mt Kenya, Mt Elgon, the Aberdares Range, Cherangani Hills, Tugen Hills, Mau Range, Timboroa, Nandi and Kakamega Forests. It is mostly found in association with species such as *Albizia gummifera, Aningera adolfi-friederici, Cassipourea malosana, Celtis africana, Podocarpus falcatus* and *Polyscias kikuyuensis*. The species has a high light requirement and grows best in forest gaps (Orwa, *et al*., 2009).

The tree species is widely known for its medicinal value, control of soil erosion, high quality firewood, mulch and green manure, bee forage and shade (Maundu and Tengnäs, 2005). It is also used for structural and furniture timber, poles and making mortars. In the recent past, *P. Africana* has been overexploited as its bark has a high cash value in the international trade as a remedy against prostate disorders, leading to the species being threatened with extinction (Cunningham *et al.,* 1997; FAO, 1996). The harvest of mature, seed producing trees severely reduces natural regeneration and destroys the natural resource base in collection areas thereby interfering with production of seedlings. The tree is restricted to areas with altitude of 1000 m and above, grows slowly, has recalcitrant seeds and does not maintain a large seedling bank in the forest under storey posing a great problem in regeneration in the natural environment. Natural populations of *Prunus africana* also present management problems because of low and patchy stocking levels and the frequent under-representation of small individuals.

There is therefore need to conserve the species. One of the recommended ways of conserving this species is through its domestication. "Domestication of trees involves accelerated and human-induced evolution to bring species into wider cultivation through a farmer-driven or market-led process. Domestication is an interactive procedure involving; identification, production, management and adoption of desirable germplasm" (Leaky and Simons, 1997). Since the farmers have vested interest on the crops and trees they grow, the deliberate cultivation of *P. africana* on their farms potentially promises a sustained supply of its products. This will be motivated by the cash value of the bark and the security of future harvests. However, its introduction into the farms is bound to face some challenges and hence the need to assess the level, potential and constraints to its domestication in some areas that the species is naturally found. The overall goal was to generate information for improving conservation and domestication of *Prunus africana* on farms in Kenya. The specific objectives were to assess the domestication level of *P. africana* and other common tree species on farms adjacent to South Nandi/ Kobujoi and Kakamega forest reserves and also to identify the potentials and constraints for growing *P. africana* on farms adjacent to Kobujoi and Kakamega forest reserves.

Materials and methods

Study sites

The study was conducted on farms adjacent to Kobujoi and Kakamega forests in western Kenya. The sites were selected on the basis of natural availability and ecological distribution of *Prunus africana* together with the geographical and cultural or user differences of people living adjacent to the forest reserves involved in the survey.

Farm survey

Farm survey was conducted to assess the distribution, use and constraints of domestication of *P. africana* in the farms adjacent to Kobujoi and Kakamega forest reserves. The survey was aided by the use of a semi-structured questionnaire. A total of 72 farmers (36 each from both Kakamega and Kobujoi) were interviewed and the answers given were incorporated with the general observations made in the farms. In addition to filling the questionnaires, physical counting for all *P. africana* trees growing on farms was made. The data was analyzed using statistical package for social sciences (SPSS) and presented in graphs and tables.

Sampling procedure in farms selection

A stretch of about 10 kilometers running along Kobujoi forest edge was demarcated. A second stretch of the same length (10 km), was demarcated about 2.5 kilometers from the forest edge while the third transect was made about 5 kilometers from the forest edge (Figure1). For every transect, 12 farms were sampled systematically (after every 0.8 km) and used for the survey. Similar stretches were demarcated on farms adjacent to Kakamega forest reserve (Figure 2).

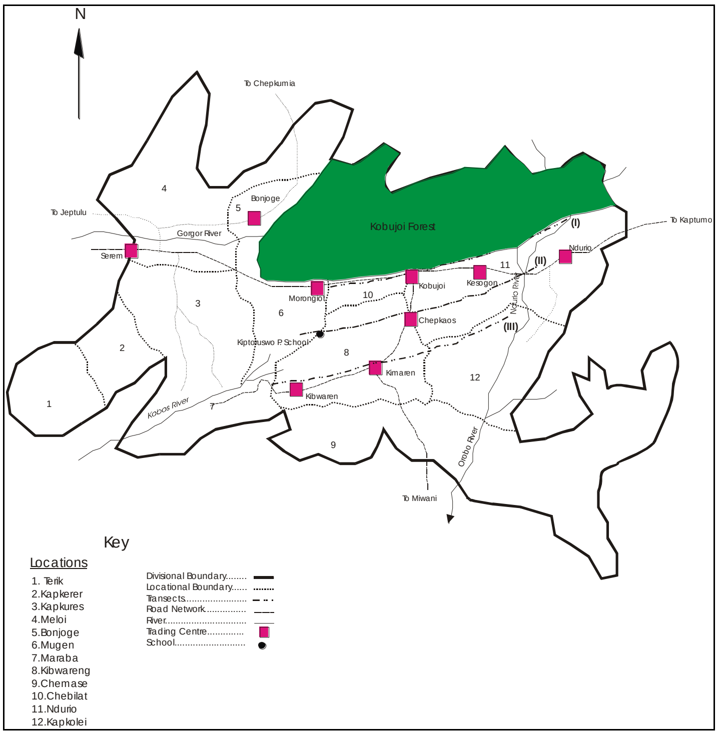

Figure 1. Kobujoi forest and the position of the three transects (I, II, III) used for the farm survey

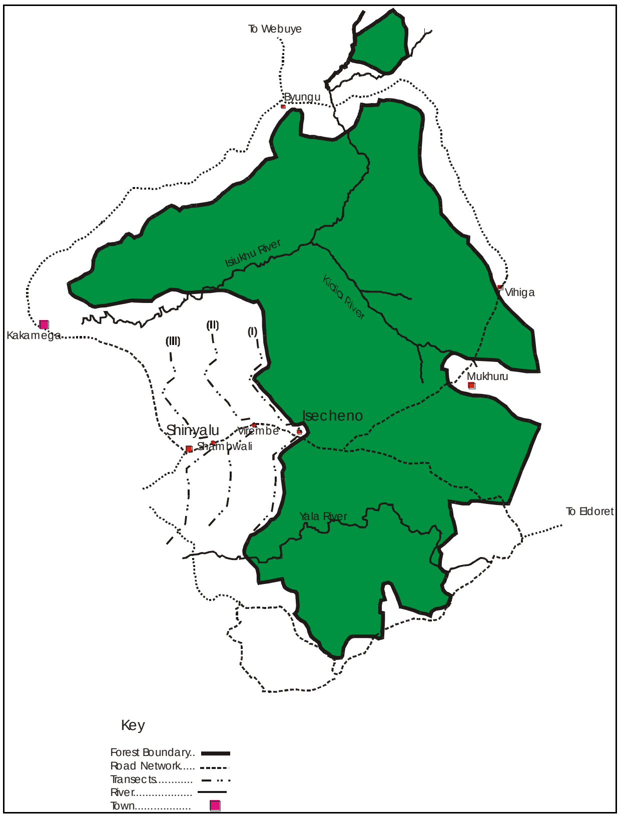

Figure 2. Kakamega forest and the transects (I, II, III) used for the farm survey

Results and discussion

Level of trees domestication in Kobujoi and Kakamega forest areas

In all the sampled farms adjacent to Kobujoi and Kakamega forest areas, tree farming was prevalent. Kobujoi, however, had more tree species (57) than Kakamega (49). Some 31 tree species were common in both areas in varying intensities (Appendix). Generally, Kobujoi observed more farmers (69%) who had *P. africana* on their farms than Kakamega area (56%). The most commonly grown tree species present in both areas include *P. africana*, *Croton macrostachyus*, *Cupressus lusitanica*, *Eucalyptus spp*, *Markhamia lutea*, *Persea americana* and *Zanthoxyllum gillettii* (Tables 1 and 2)

Table 1. Ten most frequently occurring tree species in farms adjacent to Kobujoi forest reserve and their uses

	% of farmers reporting the use of tree species as:							
Tree species	CC	FW	CN	FC	MD	SD	TB	FR
Croton macrostachyus	31	83	3	6	42	56	44	0
Croton megalocarpus	39	92	6	11	14	47	47	0
Cupressus lusitanica	0	58	22	33	0	17	72	0
Eriobotrya japonica	0	44	0	8	0	33	0	56
Eucalyptus spp	3	81	36	42	0	0	75	0
Markhamia lutea	3	53	33	22	8	22	44	0
Persea americana	0	25	0	0	0	31	0	44
Polyscius fulva	0	47	3	0	3	11	47	0
Prunus africana	11	64	3	11	28	11	61	0
Zanthoxyllum gillettii	6	47	0	0	47	0	58	0

Key

FW = Fuelwood SD = Shade CN = Construction poles TB = Timber
FC = Fencing FR = Fruits MD = Medicine CC = Charcoal

Table 2. Ten most frequently occurring tree species in farms adjacent to Kakamega forest reserve and their uses

	% of farmers reporting the use of tree species as:							
Tree species	**CC**	**FW**	**CN**	**FC**	**MD**	**SD**	**TB**	**FR**
Croton macrostachyus	53	83	0	0	11	11	58	0
Cupressus lusitanica	3	72	22	19	0	0	78	0
Eucalyptus spp	3	81	31	28	3	0	86	0
Grevillea robusta	8	44	3	0	0	3	50	0
Mangifera indica	0	31	0	0	0	6	0	42
Markhamia lutea	0	44	31	28	6	3	56	0
Olea capensis	8	44	0	0	50	0	50	0
Persea americana	3	58	0	0	0	8	3	75
Prunus africana	19	44	3	0	17	0	50	0
Zanthoxyllum gillettii	17	50	0	0	64	0	64	0

Key
FW = Fuelwood SD = Shade CN = Construction poles TB = Timber
FC = Fencing FR = Fruits MD = Medicine CC = Charcoal

A study by Madofe *et al.* (2006) in Tanzania indicates that *P. africana* is among the most preferred species, ranking fourth amongst ten most preferred trees in the study area. Other important trees mentioned by respondents were *Cordia africana*, *Grevillea robusta* and *Cupressus lusitanica* . In Cameroon, Franzel, *et al*. 2010, found that *P. africana* is mostly cultivated as a cash earning enterprise, an important medicine for home consumption and other multiple products such as handles for axes and hoes, mulch and green manures, firewood, poles and seed sales.

Occurrence and planting niche of *P. africana*

Total planted *P. africana* trees were 94 while natural stock was 81 both in Kakamega and Kobujoi. Kakamega area has many of this tree species than Kobujoi (Table 3). Main planting niches for Kobujoi forest are on boundaries, watershed and on farm in a scattered manner. In Kakamega, *P. african*a is mainly planted on boundaries, on farm (scattered) and as woodlots (Table 4).

Table 3. Nature of occurrence of *P. africana* by farm holdings in Kobujoi (n = 25) and Kakamega (n = 20) forest areas

	% of farmers where the species occurred		
Study site	**As planted stock**	**Naturally**	**Both planted and naturally**
Kobujoi	44	36	20
Kakamega	50	45	5

Table 4. Main planting niche of *P. africana* on farms in Kobujoi (n = 111) and Kakamega (n = 77)

	Proportion (%) of *P. africana* trees at:	
Planting niche	**Kobujoi**	**Kakamega**
Boundary planting	58	51
Trees on watershed areas	20	9
Trees scattered on the farm	14	27
Trees on homestead	8	1
Woodlot	0	12

According to the respondents of Kakamega, the tree is not supposed to be planted but rather should grow naturally. If planted, it was a bad omen and associated with death of members of the concerned family. For the same reason, it was also not allowed to grow near a homestead. That is why there is minimal growth of *P. africana* near homestead in Kakamega. Elsewhere, according to Franzel, *et al*, 2010, *P. africana* was commonly mixed with other species in woodlots (4 out of 10 farmers) on land where crops had not performed well. Other reported common niches, included in coffee plantations, on boundaries, and scattered in food crops.

Factors influencing planting/retention of *P. africana* on farms

Farmers knowledge of the use of *P. africana*

The data collected indicate that farmers in Kobujoi are more aware of *P. africana* uses than those in Kakamega (Table 5). Firewood recorded the highest frequency of use in Kobujoi while timber was cited highest in Kakamega. Kobujoi farmers had extra knowledge of the species uses than those from Kakamega. The extra knowledge comprised of the species reported provision of shade, fencing material, mulch, bark sale and spearhead poison in Kobujoi.

Table 5. Utilization or use knowledge of *P. africana* by farmers living adjacent to Kobujoi (n = 36) and Kakamega (n = 36) forests

Use	% of farmers reporting a particular use of *P. africana* at:	
	Kobujoi	**Kakamega**
Firewood	64	44
Timber	61	50
Medicinal	28	17
Shade	11	0
Fencing	11	0
Charcoal	11	19
Mulch	6	0
Bark sale	3	0
Poles	3	6
Spearhead poison	3	0

As a multipurpose tree species, *P. africana* can positively contribute to the well being of the farmers. Its timber is of high quality (heavy, hard, tough and of above-average strength) (Bryce, 1967). This makes it suitable for construction work as evident in Kobujoi and Kakamega areas. The same quality makes it preferred for fencing in Kobujoi. Firewood is another basic use of *P. africana* both in Kobujoi and Kakamega as it is the main source of energy for cooking food. This is in line with most of Kenyan rural population, of which 80% uses fuelwood as a source of fuel in their food preparation and warming their houses (Hankins, 1989). The species makes excellent firewood because its wood burns for long periods of time at high intensity (Cunningham, 1995). Due to its evergreen character, *P. africana* is used in Kobujoi area to provide shade, acts as an ornamental tree and protects buildings from strong winds when planted on homesteads.

Forests and trees in particular, play a crucial role in health of many people (Suda, 1992). The use of local drug plants varies from species to species, from distance to distance, from place to place, from time to time and even from person (medicine man) to person (Kokwaro, 1976). There are, of course, many similarities in the utilization of the plants as well. The Nandis and the Luhyas living in Kobujoi and Kakamega respectively, have a wide indigenous knowledge of medicinal trees (Table 1 and 2). More farmers from Kobujoi (26 %) were aware of the species medicinal value than in Kakamega (17 %). *Prunus africana's* use for medicinal purposes ranked third in both study areas, only after *Z. gillettii* and *C. macrostachyus* in Kobujoi and *Z. gillettii* and *O. capensis* subsp *welwitschii* in Kakamega. Elsewhere, according to Jeanrenaud (1991) and Cunningham and Mbekum (1993), *P. africana* is the fourth most important traditional medicinal plant species in Cameroon.

Some diseases reported to be treated using *P. africana* by the locals were similar in both places (stomach ache and chest pain), while others were site specific (Table 6). Elsewhere, in Oku, traditional doctors use some *P. africana* bark in preparing nearly all traditional medicines; it is especially important in cures for stomach ailments ('belly bite'), fever, rheumatism, and gonorrhea. Nsom and Dick (1992) have recorded *P. africana* as an important medicine for treating malaria, stomach ache and fever in the Ijim/Kom area. Use of the bark to treat stomach ache is also recorded from East Africa (Kokwaro, 1976) and in Cameroon (Letouzey, 1978).

Table 6. Cited medicinal value of *P. africana* by farmers living adjacent to Kobujoi and Kakamega forests

Study area	**Diseases reported to be treated by *P. africana***
Kobujoi	(a) Human: Stomach ache (9%), prostate cancer (4%), gonorrhea (3%), liver (3%), chest pain (3%), cold (3%), asthma (3%). (b) Livestock (cattle): Indigestion (3%), diarrhea (3%), placenta disorders (3%), East Coast Fever (3%).
Kakamega	(a) Human: Stomach ache (12%) and chest pain (5%).

The reliance of indigenous forests as sources of the bark is not sustainable and need to be supplemented by planting the species both in government forests (as enrichment planting and plantation) and on farms. The price of *P. africana* bark is; however, low to entice the farmers in its cultivation. One buyer was reported buying the bark from the farmers at KES 300 (US$ 3.75) per one-ton pickup. There is therefore need to develop the bark's market. The sale of *P. africana* seedlings and/ or seeds can also be a profitable venture for small-scale farmers. In Cameroon, a farmer was documented selling the seeds for US$ 8 per kilogram (Dawson and Fondoun, 1996).

Land size and cultivation level of P. africana on farms

Majority of the farmers in the study areas are small-scale holders with less than four hectares of land (Table 7). The case is more pronounced in Kakamega where about 89% of the sampled farmers had two or less hectares of land. The average farm sizes in Kakamega county is 1.5 acres for small scale holders (county government of Kakamega, 2015) https://kakamega.go.ke/economy). Cultivation of *P. africana* was higher in the smaller farms ($\leq$ 2.0 ha) than in the large farms (negative correlation of r = -0.33 for Kobujoi and r = -0.81 for Kakamega area).

Table 7. Relationship between land size and level of *P. africana* cultivation in Kobujoi and Kakamega

Farm size (ha)	**Proportion (%) of interviewed farmers with a given land size cultivating *P. africana* at:**		**Proportion (%) of *P. africana* trees on farms at:**	
	Kobujoi (n = 36)	**Kakamega (n = 36)**	**Kobujoi (n = 111)**	**Kakamega (n = 77)**
≤ 2.0	42	89	18	92
2.1-4.0	41	6	68	3
4.1-6.0	3	3	1	4
> 6.0	14	3	14	1

According to ANOVA, the different farm sizes had significantly different ($P < 0.05$) number of *P. africana* trees in both Kobujoi and Kakamega (Table 8). Farmers having middle size farms (2.1 – 4.0 ha.) had significantly higher ($P < 0.05$) number of *P. africana* trees in Kobujoi than the small land size farmers (≤ 2.0 ha.) and the big land size (more than 4.0 ha) farms. At Kakamega, it was those farmers with small farms (2 hectares or less) who had significantly higher ($P < 0.05$) number of *P. africana* on their farms than the farmers with bigger farms (over 2 hectares pieces of land).

Table 8. The density and mean number of P. africana trees in relation to farm sizes at Kakamega and Kobujoi

Farm size (ha)	Density (trees ha^{-1}) of *P. africana* trees		Mean number of *P. africana* trees	
	Kobujoi	Kakamega	Kobujoi	Kakamega
≤ 2.0	**1.2**	**2.2**	**0.60_a**	**1.94_a**
2.1 – 4.0	**1.5**	**0.3**	**2.11_b**	**0.06_b**
4.1 – 6.0	**0.2**	**0.5**	**0.03_a**	**0.08_b**
> 60	**0.3**	**0.1**	**0.42_a**	**0.03_b**

Note: Means with similar letters indicate that there was no significant difference ($P > 0.05$, DMRT)

The higher trees density in Kakamega could have been due to the fact that it had more small scale farmers (with ≤ 2.0 ha) than Kobujoi. Such farmers have a tradition of practicing agroforestry than large-scale farmers. Their small land divisions have many boundaries, which were cited in the study, as most preferred niches for tree planting. The findings are in agreement with Harrison and Herbohn (2005), who concluded that forestry is less popular on the larger and commercially viable farms than on smaller holdings of similar land type, and plantation establishment is often supported by off-farm income, so that farm fragmentation may actually lead to increased tree planting.

Constraints faced by farmers in domesticating *P. africana*

Despite the enormous agronomic potential of agroforestry species and methodologies, adoption in sub-saharan Africa remains low (Kiptot *et al* 2007). In both Kakamega and Kobujoi, several constraints inhibiting the cultivation of *P. africana* were reported (Table 9).

Table 9. Constraints faced by farmers in domesticating *P. africana* in Kobujoi (n = 36) and Kakamega (n = 36)

	% of farmers citing a particular constraint at:	
Constraint	**Kobujoi**	**Kakamega**
Competition with crops	53	22
Lack of seedlings	39	36
Destruction by livestock	17	17
Pests and diseases	14	0
Destruction by children	14	0
Small land size	14	22
Slow growth of the species	14	14
Drought	11	14
No interest/ reason	11	3
The farmer had just settled	8	3
Land tenure	6	0
Lack of knowledge of its importance	6	0
Customs and beliefs	3	39
Difficulties in identifying planting site	3	0
Already have enough trees in the farm	3	0
Expensive nursery practices	0	3
Lack of time	0	3

In Kobujoi, the species competition with the agricultural crops was cited as the main constraint. Elsewhere, in Cameroon there appeared to be little if any competition between *P. africana* trees and crops (beans, coffee, and potatoes) while on other farms considerable competition with crops, notably maize, growing near the tree was noted (Stewart, 2003). Competition for light, water, nutrients and space between the agricultural crops and *P. africana* trees can be minimized to tolerable levels. Regular pruning, pollarding and/or lopping of the trees will ensure that their crowns are reduced thereby reducing their shading on the under-growing crops. Wide spacing of trees could be maintained if they are to be scattered on the farms and along boundary lines. Thinning may also be done if the tree density is already high.

In Kakamega, certain customs and beliefs associated with the species discouraged the farmers from cultivating it (Table 5). According to the respondents, the tree was not supposed to be planted but rather should grow on its own. If planted, it was a bad omen and associated with death of members of the concerned family. For the same reason, it was also not allowed to grow near a homestead. Chavangi (1989) also noted that in Kakamega, it is believed that if a woman plants trees, her husband will die, or that she will be barren. Since traditionally child bearing is an important requirement of stability in marriage, no woman would dare plant trees for fear of becoming barren. Older women who already have the number of children they want, can, however, plant trees and often do so. Similarly, no woman would plant trees if doing so is seen as a threat to her husband's life. In the same community, *C. macrostachyus* is a common tree species and highly valued for its ability to provide fire especially during the mourning period. Taboos and beliefs related to trees – both positive and negative, have been cited as factors to be considered in tree cultivation by Foley and Geoffrey (1984). The communities should therefore be encouraged to practice positive tree-cultivating related taboos/ beliefs and more research to verify the facts regarding the negative ones need to be done.

Many farmers in the study areas cited lack of seedlings as a major constraint in cultivating *P. africana*. The species has seed storage problems thereby making them difficult to propagate (Sunderland and Nkefor, 1997). This hinders the international exchange of seeds and the nursery production of seedlings, as well as farmers' plans to plant the species. This can be solved by sowing fresh seeds which germinate readily (Geldenhuys, 1981) or use of wildings. Expensive nursery practices reported in Kakamega was also reported in Oku area, Cameroon in terms of scarce and high costs of polythene tubes, much labor especially for watering and theft of seedlings (Franzel, *et al*., 2010).

Farmers termed drought as another major constraint to tree planting. The actual constraint could, however, have been the competition for labor between planting of agricultural crops and trees. Since the two activities are supposed to be carried at the same time, agricultural crops are given priority and trees are planted when the rainfall has reduced. Lack of enough land, farm layout and land tenure are other major obstacles to growing *P. africana* among the peasant farmers, since the species occur in high potential areas where land is usually scarce. Elsewhere in eastern Zambia, researchers characterize adoption of agroforestry technologies as a function of socio-economic factors such as wealth, gender, labor availability or farm size (Franzel *et al.,* 2002; Ajayi *et al.,* 2007). Insecurity of tenure or unclear rights to land, are strong disincentives to all forms of long-term investment, including tree growing (Tengnäs, 1994). Since men are regarded as the owners of the land the family occupies (Tengnäs, 1994), women rarely have power to long term investment such as tree planting. In such cases, it is not only unattractive to invest in tree planting if you are not sure of getting the benefits of the investment, but it may also be unacceptable to plant trees on land which has not legally been confirmed as belonging to the user (Tengnäs, 1994).

Grazing animals do interfere with on-farm *P. africana* trees through browsing (as the species is palatable) and trampling on seedlings and saplings, a problem also reported by farmers in Cameroon (Hall *et al.*, 2000). Other problems reported in Cameroon include stem borer, especially in lower altitudes, aphids on seedlings in nurseries, theft of bark and seedlings. This can be minimized by fencing around nurseries and young tree seedlings or encouraging farmers to plant trees in woodlots that are protected from livestock. Most farmers in Kobujoi and Kakamega lack knowledge of the existence of *P. africana's* bark trade. Where trade exist, the price of the bark is very low, ranging from 0.6 – 0.7 US$ and 2.0 US$ per kg in Cameroon and Kenya, respectively (Cunningham and Mbenkum, 1993). This is quite low to motivate the farmers and other bark harvesters. A farmer in Kobujoi said that the only buyer of *P.africana* bark was buying the bark at a throw-away price of KES 300 per one-ton pick-up (Pers. com). Elsewhere in Mau, farmers were clearing their forest, cutting down *P. africana* for quick cash from its charcoal and pave way for agricultural practices (tea plantations) (Ndam and Ewusi, 1999). When compared with *Acacia mearnsii* commercially cultivated for tanning, the price of *P. africana* bark is a thousand times more costly than that one of *Acacia mearnsii* (Cunningham, 1995). So, if the marketing can be organized the species can be of great value to farmers.

P. africana farming may also pose another problem. The tree takes long to mature and start having some tangible benefits. Farmers in both Kakamega and Kobujoi cited the slow growth of the species as one of the major constraints discouraging its domestication. According to Lodoen (2000), *P. africana* takes 12-15 years before the bark contains the active ingredients that treat BPH. The species has, however, been described as a fairly fast growing indigenous tree, comparable with *Acacia mearnsii,* a fast growing species commercially grown for tannin production (Cunningham *et al.,* 1998). An alternative to waiting for over 12 years before harvesting the bark would be for farmers to cultivate only young *P. africana* trees (2-3 years old) for the extract processing. This would give farmers a shorter rotation crop to cultivate, but feasibility depends on the level of active ingredient in the young trees, which discredit this possibility (Lodoen, 2000).

Conclusions and recommendations

Generally, farmers adjacent to both Kakamega and Kobujoi forests have a wide range of tree species in their farms, with *P. africana* being a priority species for domestication in the two areas. Due to its multiple uses in the studied areas, there is the need for ethnobotanical surveys to document more detailed information about *P. africana* throughout its ecological range. Its use in treating BPH and subsequent value of its bark is not widely known to the communities. This calls for community enlightening on this valuable information as it could entice more farmers to conserve the species. This should also go hand in hand with development of the bark trade. The various constraints associated with on-farm conservation of *P. africana* need to be addressed. The use of wildings for propagation should be encouraged together with capacity building on nursery establishment and management. The communities should be encouraged to continue nurturing the trees in their preferred planting sites (farm boundaries, watersheds) and trees scattered on farms need to be well spaced and pruned regularly to minimize their competition with growing crops. In Kakamega, the community should be educated to dissociate the species with bad omen. Despite small land sizes being mentioned as one of the constraints facing the domestication of *P. africana*, it is clear from the study that farmers with small land sizes had more *P. africana* trees than the ones with big farms.

Acknowledgement
The authors really thank the World Agroforestry Centre (ICRAF) for providing funds. Several local guides and farmers in both Kakamega and Kobujoi for providing the useful information, Moi University and ICRAF staff who participated in data collection, analysis and report writing as well as supporting logistically. To all God bless.

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Appendix

Farmers' tree domestication level in Kobujoi (n = 36) and Kakamega (n = 36) forest areas

Tree species	**% of farmers with the tree species**		**Tree species**	**% of farmers with the tree species**	
	Kobujoi	**Kakamega**		**Kobujoi**	**Kakamega**
Acacia mearnsii	8	0	*Hekea saligna*	3	0
Acacia melanoxylon	6	0	*Jacaranda mimosifolia*	14	28
Acacia seyal	6	0	*Juniperus procera*	3	3
Acrocarpus fraxinifolius	3	8	*Khaya senegalensis*	0	3
Albizia gummifera	22	0	*Kigeria africana*	8	6
Aningeria altissima	0	6	*Leucaena leucocephala*	6	0
Azadirachta indica	8	6	*Macaranga kilimandiscarica*	3	0
Bersama abyssinica	28	0	*Macrocapus spp*	3	0
Bischovia javanica	0	33	*Maesopsis eminii*	0	39
Bombx spp	0	3	*Mangifera indica*	22	44
Bosquiea phoberus	0	3	*Markhamia lutea*	72	75
Brideria mycrantha	0	42	*Newtonia buchananii*	11	0
Casaeria balticosmbei	3	0	*Ocotea usambarensis*	8	0
Casuarina equisetiflia	14	17	*Olea africana*	0	3
Calliandra calothyrsus	0	8	*Olea capensis*	17	58
Callistemon citrinus	3	28	*Persea americana*	83	78
Carrisa edulis	3	0	*Phoenix reclinata*	8	0
Celtis africana	19	0	*Pinus patula*	6	36
			Podocapus falcatus	11	6
Cordia africana	0	17	*Polyscius fulva*	56	8
Croton macrostachyus	89	86	*Prunus africana*	69	58
Croton megalocarpus	94	17	*Psidium guajava*	44	36
Cupressus lusitanica	78	83	*Rhus natalensis*	3	0

Tree species	% of farmers with the tree species		Tree species	% of farmers with the tree species	
	Kobujoi	Kakamega		Kobujoi	Kakamega
Delonix regia	0	3	*Ricinus communis*	28	6
Diospyros abyssinica	8	3	*Salvadora persica*	3	0
Dovyalis abyssinica	8	0	*Sesbania sesban*	3	3
Drypetes gerrardii	3	0	*Spathodea campanulata*	28	0
Eriobotrya japonica	53	33	*Strombosia scheffleri*	3	0
Erythrina abyssinica	11	6	*Teclea nibilis*	3	0
Eucalyptus spp	86	97	*Terminalia mentalis*	6	31
Euphorbia candelebrum	11	0	*Trema orientalis*	0	3
Fagaropsis angolensis	31	3	*Trichila loci*	11	3
Fantumia latifolia	0	22	*Trichila strigulosa*	0	6
Ficus thonginii	25	22	*Vangueria madagascariensis*	44	0
Fraxinus pennsylvanica	3	0	*Vitex keniensis*	0	8
Grevillea robusta	39	53	*Warbugia ugandensis*	0	3
Hagenia abyssinica	6	0	*Zanthoxylum gillettii*	58	81
Harungana madagascariensis	0	3			

Towards a Sustainable Management of Invasive Alien Trees and Shrubs in Eastern Africa: The 'Woody Weeds' Project

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Abstract

A reconnaissance survey was undertaken in Kitui and Makueni counties where the Social Forestry Extension Model Development Project (SOFEM), Intensified Social Forestry Project (ISFP) and Agroforestry for Integrated Development in Semi-Arid Areas of Kenya (ARIDSAK) project are being implemented. This was with a view to identify the socio-economic factors influencing adoption of forestry technologies. Data was collected using a semi-structured questionnaire administered to a total of 324 farmers who were randomly selected from both the study Counties. Key informants from Kenya Forest Service and the departments of Agriculture in all the sites were also interviewed using a checklist. Data was analyzed using SPSS version 21 and Excel computer software programs, and subjected to descriptive statistics involving computation of frequency, means and percentages. The field results were presented by use of graphical and tabular techniques. The results of the study indicated that, the drivers of adoption of forestry/agroforestry technologies across the study sites were; boundary conflicts (50.2 %), fuel wood shortages (24.8 %) and strong winds (5 %). Other drivers were to diversify income sources (5 %), high temperatures (10 %) and timber shortage (5 %). The sources of forestry/agroforestry technologies information and technical backstopping were reported to be from Kenya Forestry Research Institute (50%), Ministry of Agriculture (20 %), Kenya Forest Service (15 %) and NGOs (10 %). Other sources of information (5 %) include chiefs' barazas, local radio stations, newspapers and farmer exchange programs. Forestry/agroforestry is a means of increasing food production and wood availability, hence playing a vital role in poverty alleviation and improvement of living standards in drylands.

Key words: Social Forestry, Technology, Adoption, Drivers, information dissemination

Introduction

The Arid and Semi-arid Lands (ASALs) of Kenya are characterized by numerous woods/bushes. Historically, rural populations in these areas never had to plant trees, as they were able to obtain them from the natural woodlands. The ASALs, however, are particularly coming under intense pressure due to population growth, expansion of agriculture and pasture, and development of infrastructure. The demand for natural resources is recognized as one of the major driving forces for reducing wood biomass in these areas. High level of poverty is known to be an acute issue and a driving force exerting pressure on the dryland natural resources. The situation in drylands have gained attention from various sectors of the nation and working with the affected communities to reverse the situation.

The vast majority of the Arid and Semi-arid communities are now engaging in forestry/agroforestry activities and therefore efforts are often geared towards improving forestry/agroforestry activities as a means of increasing productivity, efficiency and, ultimately, income. Besides, forestry/agroforestry also offers a number of service functions such as soil erosion control, and maintenance and improvement of soil fertility (Young, 1997). Other service functions include reduction of wind speed, weed control and live fencing. Adoption of agro-forestry, therefore, has the potential to halt land degradation and improve soil fertility. When trees are properly managed and integrated into farming systems, they improve agricultural productivity and maintain environmental integrity. Several technologies have been tested in the drylands including forestry/agroforestry technologies through extension models. Forestry/agroforestry extension models were mostly focusing on solving technical problems, such as providing nursery skills, introducing new tree species, or technology such as improved stoves.

In Kenya, Forestry/Agroforestry has received much attention in recent development efforts in the drylands. This has been reflected in numerous projects that were aimed at supporting the tree-growing efforts and other farm-based activities of the communities. Several ministries notably Ministry of Environment and Natural Resources (MoENR),) and other government extension (Tengnas B., 1994) made efforts to promote the adoption of forestry/agroforestry technologies by farmers. The efforts were put in different regions across the drylands of Kenya for instance Kitui and Makueni. In the past 10 years, Kenya Forestry Research Institute in collaboration with the Government of Belgium and Japan international Cooperation Agency (JICA) initiated various forestry/agroforestry projects to ameliorate degradation state and increase tree cover in the drylands through on-farm tree growing and other farm-based activities using selected extension models. Hence, adoption of forestry/agroforestry technologies was successfully undertaken through Social Forestry Training Project (SFTP), Social Forestry Extension Model Development Project (SOFEM), Social Forestry Project in semi-arid areas of Kenya (ISFP) and Agroforestry for Integrated Development in Semi-Arid Areas of Kenya (ARIDSAK).

The Social Forestry Training Project (SFTP) was implemented between 1985 and 1997. Its focus was to develop tree nurseries and planting technologies for the ASALs and to train stakeholders on social forestry. Social Forestry Extension Model Development Project (SOFEM) was implemented from 1997 to 2001. SOFEM aimed at developing an extension model in promoting the establishment of farm-forestry amongst communities in the ASAL areas of Kenya. The project was succeeded by the Intensified Social Forestry Project in semi-arid areas of Kenya (ISFP) in 2004 until 2009. ISFP aimed at consolidating past efforts in social forestry development and enhancing the capacity of farmers/farmer groups, Kenya Forestry Service (KFS) and other stakeholders to promote farm forestry

Agroforestry for Integrated Development in Semi Arid Areas of Kenya (ARIDSAK) was a bilateral project implemented in Makueni and Kajiado Counties and funded by the governments of Kenya and Belgium. The project used a research and development approach on-station where technologies were developed and tested by specialists. Promising technologies were further verified under farmers' conditions. Proven technologies were then packaged in the form of extension materials for use by extension staff and farmers within the project areas. Through this approach, neighbouring farmers were expected to benefit through learning experiences of democratically elected farmers.

Elsewhere in many parts of the world, despite technological advances, forestry extension has experienced uneven success due to inadequate adoption rates or abandonment of the technologies (Subhrendu *et al*., 2003). However, adoption and dissemination of forestry/agroforestry technologies is complex due to a number of reasons including uncertainty, cost and benefits of the technology, gender, social capital, socio-cultural practices, high costs of labor, access to markets, and credit among others (Phiri D., 2004; Rao E.J.O. *et al*., 2010; Nordin S.M., *et al* 2014). However, there are socio-economic and biophysical factors that variously influence the adoption of the forestry/agroforestry technologies. Socio- economic factors such as education level, income level, farm size and family size influence greatly the adoption rates of forestry / agroforestry across the communities (Onyango, 1993). In this study, a reconnaissance survey was conducted in the Kitui and Makueni Counties to access the level of adoption of forestry/agroforestry technologies developed over the projects' period under SOFEM, ISFP and ARIDSAK. The objectives of the study were to identify the socio-economic factors influencing adoption of forestry/agroforestry technologies, identify and assess the drivers of adoption and assess how adoption of the technologies varied by extension approach, technology characteristics and social setting. In addition, sources of information on forestry/agroforestry technologies would be identified, and recommendations on extension approaches applicable in different situations given.

Methodology

Study sites

The study was undertaken in Kitui and Makueni County in the Eastern region targeting the general population of core farmers, SOFEM and ARIDSAK trainees. Kitui County is located between latitudes 0°10' and 3°0' South and longitudes 37°50' and 39°0' East. It has a low lying topography with arid and semi-arid climate (Government of Kenya, 2014). It covers an area of 30,496.4 km^2 including 6,369 km^2 occupied by Tsavo East National park. The County borders seven counties: Machakos and Makueni to the west, Tana River to the east and south-east, Taita Taveta to the south, Embu to the north-west and Tharaka-Nithi and Meru to the north. The altitude of Kitui County ranges between 400 m and 1800 m above sea level. Temperatures are high throughout the year, ranging from 14°C to 34°C. The hot months are between September/October and January/February. The maximum mean annual temperature ranges between 26°C and 34°C whereas the minimum mean annual temperature ranges between 14°C and 22°C. July is the coldest month with temperatures falling to a low of 14 °C, while September is the hottest month with temperature rising to a high of 34 °C. Rainfall distribution is erratic and unreliable. The annual rainfall ranges between 250 mm and 1050 mm per annum with 40% reliability for the long rains and 66 % reliability for the short rains. The population is at 1,147,200 **(Female:** 602,002, **Male:** 545,195**)** people (Kenya National Bureau of Statistics, 2009).

Makueni covers over 8,034.7 km^2 with a population of more than 900,000 people (Kenya National Bureau of Statistics, 2009). The County borders Kajiado County to the West, Taita Taveta to the South, Kitui to the East and Machakos to the North. It lies between Latitude 1^0 35´ and 3^0 00' South and Longitude $37^0$10´ and 38^0 30´ East (Government of Kenya, 2013). The terrain is low-lying from 600 m above sea level in Tsavo. The County is largely arid and semi-arid and usually prone to frequent droughts. The lower side which is very dry receives little rainfall ranging from 300 mm to 400 mm. The County experiences two rainy seasons, the long rains occurring in March/April, and the short rains occurring in November/December. The hilly parts of Mbooni and Kilungu receive 800 mm – 1200 mm of rainfall per year (Government of Kenya, 2013). High temperatures of 35.8 ^{0}C are experienced in the low-lying areas causing high evaporation that worsens the dry conditions.

Data collection and Analysis

The study employed a reconnaissance survey to collect data in Kitui County (Mutomo, Ikutha and Mutitu) and Makueni County (Kibwezi and Kathonzweni) to assess the impact and level of adoption of forestry/agroforestry technologies. Data was collected using primary and secondary methods. Primary data was collected using a semi-structured questionnaire while secondary was done through literature review from related and similar studies. The target population comprised the core farmers, trainees of the three models (SOFEM, ARIDISAK and ISFP) and general farmers. The questionnaire was administered to a total of 324 farmers (Table 1) who were randomly selected from all the study Counties. Key informants from Kenya Forest Service and the departments of Agricultural in all the sites were also interviewed using a checklist. The questionnaire was designed to gather information on socio-economic characteristic, wealth status, livelihood sources, social capital, forestry/agroforestry technologies and nursery establishment and management. Other issues were dissemination activities, sources of information, benefits and future plans. Data obtained were analyzed using SPSS version 21 and Excel computer software programs. All the data collected were summarized and subjected to descriptive statistics involving computation of frequency, means and percentages. The field results were presented by tabulation and graphics.

Table 1. Number of farmers interviewed in the study sites

Extension Model	Categories of Farmers	No. of Farmers Interviewed In 2010/2011	No. of Farmers Interviewed In 2011/2012
SOFEM	Core farmers	21	15
	Trainees	21	15
	General population	21	15
ISFP	FFS Graduates	30	6
	Trainees	25	11
	General Population	23	13
ARIDSAK	Democratic farmers	24	12
	Trainees	24	12
	General population	24	12
Sub-total		213	111
Total			**324**

Results and Discussion

Socio-economic Characteristics of the stakeholders

There were 53 % male and 47 % female respondents across the extension models (SOFEM, ARIDSAK and ISFP) model. This shows that both gender plays an important role in adoption of forestry/agroforestry technologies though men are the decision makers when it comes to implementation of the technologies. Therefore, both gender played an active role in the implementation of the projects, and consequently in the study across the study sites. The higher response in male across in the study greatly contributed to the adoption of forestry / agroforestry technologies positively. The age of the respondents was 30 to 39 (40 %), 40 to 49 (23 %), 50 to 59 (20 %) and over 60 years (17 %) respectively. It was reported that 45% of the respondents spent 4 to 6 years and 65 % spent 6 to 8 years across the study sites. Education level of a farmer is believed to create favorable mental atmosphere to for acceptance of new technologies that seem to benefit (Wafuke S., 2012); hence, in this study education played a key role. According to Amaza and Tashikalma (2003), the literacy level of farmers is important as it determines the rate of adoption of improved technology for increased productivity. In this case, it may have accelerated the adoption of forestry/agroforestry technologies due to the enhanced ability to acquire technical knowledge across the study sites. Besides, farmers who have some level of education respond readily to improved technology than those with no formal education. Adekunle (2009) pointed out that the level of education of farmers will directly affect their ability to adapt to change and to accept new ideas. A higher percentage of the respondents were married (90 %), a meagre of 7 % and 3 % were widowed and single respectively. Majority (43 %) of the respondents indicated to hold 1to 5 acres of land, 27 % (5 to 10 acres), 12% (10 to 15acres), 10 % (15 to 20 acres), 8 % (above 20 acres) respectively. Land is one of the factors required in production. Therefore, the availability of adequate land in the study sites would contribute to the adoption of forestry/agroforestry technologies (Table 2).

Table 2. Socio-economic characteristic

Variable	%
Gender	
Male	53
Female	47
Age	
30-39	40
40-49	23
50-59	20
over 60	17
Education Level	
4-6 Years	45
6- 8 Years	65
Land size (acres)	
1-5 acres	43
5-10 acres	27
10-15 acres	12
15-20 acres	10
Above 20 acres	8
Marital status	
Married	90
Widowed	7
Single	3

Forestry/agroforestry technologies practiced

A higher percentage (78 %) of the respondents in all the study sites adopted various forestry/agroforestry technologies in their farms. The technologies adopted were shade (15.3 %), windbreak (5 %), tree boundary (40.1 %), home garden/fruits (8 %), fuelwood (30.1 %) and timber/poles (2.6 %). Various tree species were used for different technologies such as *Melia volkensii*, *Senna siamea*, *Grevillea robusta* and *Mangifera indica*. Lionberger explained that farmers prefer different forestry/agroforestry technologies based on farm size and the direct benefits to their well-being. Therefore, most farmers adopted tree boundary technology because of the vast benefits would be obtained (Table 3). The most common drivers of adoption of forestry/agroforestry technologies across the study sites boundary conflicts (50.2 %), fuel wood shortages (24.8 %) and strong winds (5 %). Other drivers were diversify income sources (5 %), high temperatures (10 %) and timber shortage (5 %).

Table 3. Trees species adopted by farmers

Tree species	Frequency	Percentage
Melia volkensii	29	30
Senna siamea	12	24
Mangifera indica.	11	20
Azadirachta indica	10	5.0
Grevillea robusta	13	13
Total	**72**	**100.0**

Planting Material sources

There was an active involvement in planting materials/seeds collection across the study sites for implementation of the forestry/agroforestry technologies. Planting materials/seeds were obtained from various sources such as collecting from existing forests (51 %), purchase from local vendors (19 %) and on-farm collection (30 %). An active participation was seen in nursery establishment and management; 55 % of the respondents had own nurseries, while the rest (45 %) had none. A majority of those who owned nurseries had individual nurseries (75 %), while 25 % were in nursery groups. The respondents raised planting materials/seedlings for sale and individual use; 65 % sold the planting materials/seedlings while 45 % raised them for personal use. The seedlings raised in the established nurseries were *Senna siamea*, *Grevillea robusta*, *Mangifera indica*, *Citrus spp* and *Melia volkensii*. Respondents produced more *Senna siamea* seedlings (40 %) *Grevillea robusta* (30 %), *Mangifera indica* (15 %) and *Citrus spp* (10 %). It was noted that *Melia volkensii* (5 %) seedlings production was very low in all the nurseries compared to other species because of the technicalities associated with its extraction, storage, and sowing. However, the respondents across the sites reported to have experienced various challenges during the implementation of such activities. The stated challenges included water shortages, prolonged dry periods, pests and disease attacks, inadequate potting materials and shortages of planting materials (Figure 1).

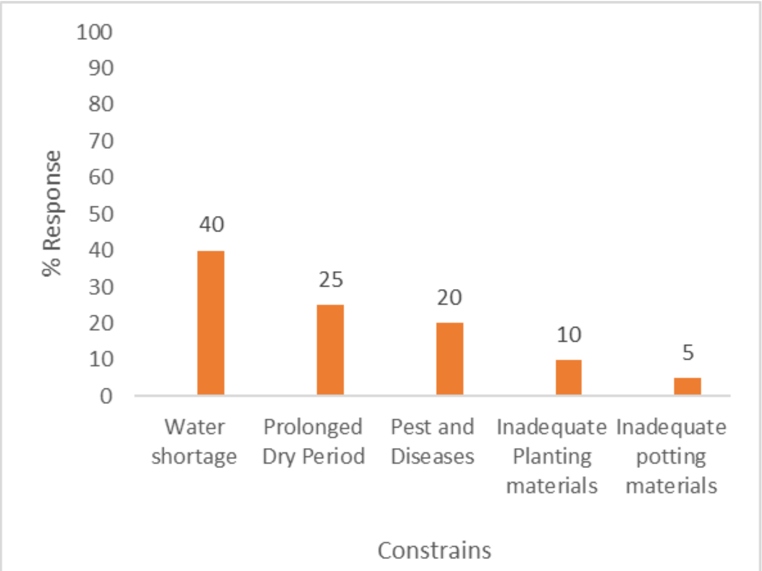

Figure 1. Contraints encountered by the stakeholders

Dissemination of forestry/agroforestry technologies

Dissemination of information is critical since it creates awareness in certain matters. It enables stakeholders to be skilled and knowledgeable in developed technologies. There was an active involvement of the respondents in dissemination activities in all the sites. It was reported that 64 % of the farmers were involved in dissemination of the forestry/agroforestry technologies through farmer-to-farmer approach. The dissemination platforms were trainings, group meetings/chiefs barazas, field days, farmer visits and demonstration plots. The most common dissemination platforms used (Figure 2) were trainings (35 %), farm visits (30 %), field days (20 %), group meetings (10 %) and demonstration plots (5 %). Various forestry/agroforestry technologies disseminated included nursery techniques (31%), grafting and budding (14 %), tree planting techniques (48 %) and horticulture (7 %). Additionally, 70 % of the farmers reported to make follow-ups with the trainees to monitor progress after their training activities while 30% did not undertake follow-ups. Sources of forestry/agroforestry technologies information and technical backstopping were reported to be from Kenya Forestry Research Institute (50 %), Ministry of Agriculture (20 %), Kenya Forest Service (15 %) and NGOs (10 %). Other sources of information (5 %) include chiefs' barazas, local radio stations, newspapers and farmer exchange programs

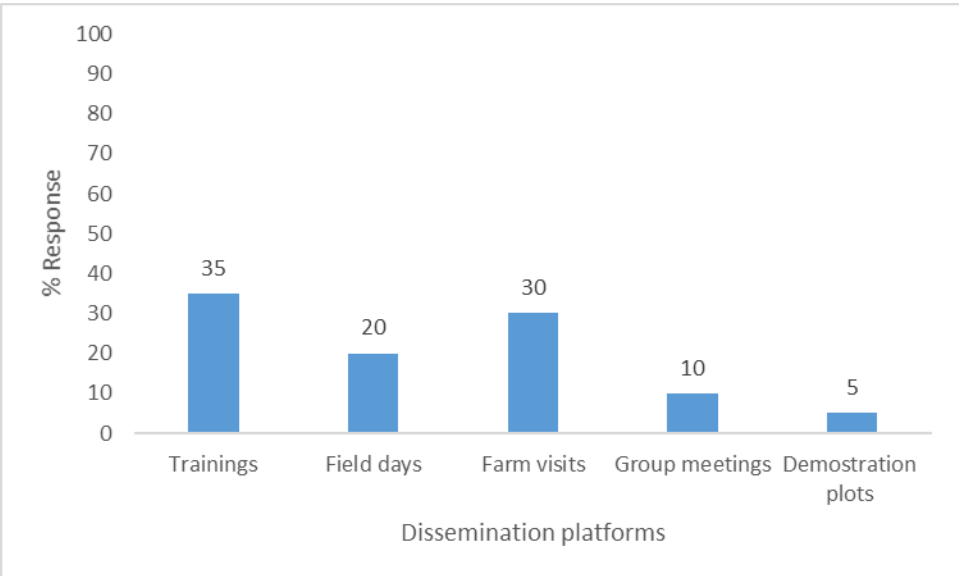

Figure 2. Dissemination platforms used by the stakeholders

Benefits of forestry/agroforestry technologies and future plans

The survey indicated that there were various benefits that accrued from the adopted forestry/agroforestry technologies included on-farm tree planting, fruit tree farming, seedlings sales from the nursery and many others. The respondents used the forestry/agroforestry technologies domestically and commercially to improve their living standards in various ways. The benefits were from poles, fruits and timber from various tree species such as *Grevillea robusta*, *Eucalyptus spp*, mango trees, and many others. Farmers greatly benefited with fruits (42.9 %), fuel wood (25.1 %), reduced soil erosion (24 %) and other benefits (8 %). The respondents earned an average profit of Ksh 1,480 (Eucalyptus), Ksh 31, 962 (Mangoes), Ksh 2,216 (Pawpaw) and Ksh 7, 2886 (Oranges) that were sold per year.

Majority of the farmers (97 %) reported to expand forestry/agroforestry activities in their farms whereas a meagre of 3% had no plans. Majority of respondents planned to plant more trees (93.8 %), maintain the existing trees (3.1 %) and join groups that produced juices for sale (3.1 %).

Conclusion and recommendations

Forestry/Agroforestry is a means of increasing food production and wood availability in drylands, hence playing a vital role in poverty alleviation and improvement of living standards among local dwellers. However, there is need to improve both formal and informal forestry/agroforestry education among rural communities for the technologies to widely be accepted. Farmers in these areas should be encouraged to practice forestry/agroforestry to benefit from crop yields and various tree products including fruits, wood, soil fertility construction materials, medicine and other unquantifiable benefits. Various platforms and strategies have been used to accelerate adoption of the forestry/agroforestry technologies though more technical support to beneficiary communities is required. Forming joint extension teams by the representative institutions that would lead to more efficient, synergic agroforestry extension approaches would be a good strategy to accelerate the adoption of forestry/agroforestry technologies. Technical assistance is needed to facilitate the spread of forestry/agroforestry. Likewise, adequate information is required to keep farmers abreast of current trends and developments in the practice of forestry/agroforestry. Provision of economic incentives to farmers participating in agroforestry practices should be considered. However, to effectively improve dryland living standards, forestry/agroforestry should form part of an integrated rural development programme and thereby meet more of the farmers' basic needs than it presently does.

Acknowledgement

The authors would wish to thank the team that was involved in the survey for their tireless efforts. We are also grateful for the financial support from Kenya Forestry Research Institute.

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THEME 4: FOREST PRODUCTS DEVELOPMENT (FPD)

KEFRI Aloe facial cream

Gum arabic on the branch

Improved Earth and Casamance Kilns for Enhanced Efficiency and Environmental Conservation

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Abstract

In Kenya, wood fuel provides over 70 % of the national energy for cooking and heating. Traditionally, production of charcoal is undertaken using the traditional earth kilns with low recovery rates (8-15 %). Harvesting of preferred tree species has led to increased deforestation and environmental degradation thus exacerbating climate change. The use of wet wood, poor stacking and poor air control are some of the factors contributing to low recovery rates. Through research KEFRI has modified the traditional earth kiln and adopted the Casamance kiln for increase efficiency. The studies were undertaken in Mbeere-North, Mwingi, Taita Taveta and Kwale Counties. The objective was to comparatively assess the production efficiency of the traditional kilns against the improved kilns and barriers to adoption of the improved technologies. Data was collected through a semi structured questionnaire and randomized designed experiment. Excel and SPSS computer packages were used to analyse data. Results showed that traditional kilns were the most preferred kilns (98 %) while 2 % use improved kilns. Lack of information and skills (88 %), high cost of the improved technologies (86 %), cultural preference (78 %), financial constraints (72 %) and high cost of transporting the heavy metal kilns and wood materials to the stationery kilns (67 %) were indicated as some of the factors influencing adoption of improved charcoal kilns. Results also indicated improved earth and Casamance kilns have higher efficiency rates of 30.5 % and 34% respectively. The study recommends increased awareness on these kilns for improved charcoal production capacities and environmental conservation; and the need for technology developers to borrow the positive aspects of traditional technologies in development of new improved technologies.

Keywords: Adoption, wood fuel, charcoal, degradation, improved technologies, overexploitation.

Introduction

Globally, demand for wood fuel is rising due to population increase and rapid urbanization particularly in Sub-Saharan Africa (SSA), where firewood and charcoal are the main sources energy for cooking and heating for over 90 % of the population. (FAO 2012, Njenga *et al*, 2013). In Kenya, Biomass energy in forms of fuel wood, charcoal and agricultural wastes is a major source of energy for millions of people in Kenya providing over 70 % of the national energy demand for cooking and heating whereby about 90% of rural households depend on firewood for cooking and heating while in urban areas 82 % depend charcoal for cooking as part of the energy mix. (Githiomi & Oduor, 2010, Ministry of Energy, 2013; World Bank 2012). Increasing poverty levels, rapid urbanization and high cost of alternative fuels such as electricity and petroleum based fuels have significantly contributed to increased demand for wood fuel. Apart from being source of fuel for domestic use, wood fuel is also an important source of energy for small and medium sized enterprises such as agro-processing industries, confectioneries, eateries, cottage Industries and institutions like hospital, prisons and schools. Its use also relates to public sector interests such as environment management, public health, rural development, employment creation and even source of foreign exchange (Githiomi, 2010) and thus wood fuel based enterprises are increasingly becoming important sources of livelihoods for both rural and urban households involved in production, transportation and sale of wood fuel products. In Arid and semi-arid areas (ASALs) which cover over 80% of Kenya Land mass, charcoal production is also an important fall back strategy especially during prolonged droughts with changing weather patterns due to climate change.

In Kenya the use of charcoal is about 47 % at the national level with use of about 82 % and 34 % of urban and rural households respectively (Ministry of Energy, 2012). As income levels of most household improve, the assumption based on the traditional energy ladder model is that biomass energy consumers are abounds to change to one clean energy source higher in the energy ladder. However, in Kenya the energy mix aspect has taken root instead, where several types of energy sources including the modern and traditional energy sources such as charcoal are increasingly being used in most rural and urban households. Due to a number of factors such as high cost of alternative clean fuels, cultural preference, availability and cost of the wood fuels, demand for charcoal is expected to persist into the future.

In Kenya, most of the charcoal is produced from the natural forested areas and woodlands using traditional earth kilns known to have low efficiency levels of between 8-15 %, (Oduor *et al.*, 2006, Ministry of Environment, Water & Natural Resources, 2013). The process of producing charcoal, a residue of solid organic matter that results from incomplete carbonization by heat in low oxygen controlled process at temperatures above 300°C, involves cutting and stacking the wood material which are then covered with green foliage and soil in mounds known as kilns. (Emrich W. 1985, Pennise *et.al*., 2001, FAO, 2009,). Use of wet wood as is the case with traditional earth kilns, extra wood is but in order to evaporate water for carbonization to commence thus poor yields and longer periods of carbonization. The efficiency levels and quality of charcoal may also be influenced by the skills of the producers and tree species being used. Continued use of traditional kilns has extensively contributed to over exploitation of preferred indigenous vegetation, a major factor to increased deforestation, loss of biodiversity, environmental degradation and global warming.

Lack of information and skills on available improved technologies, the high cost of the technologies and financial constraints among the producers has significantly affected adoption of improved charcoal production technologies in Kenya. Kenya Forestry Research Institute (KEFRI) through research and development has adapted and modified the traditional earth kiln and other adapted kilns such as the Casamance, the portable drum and the metal kiln to improve on the efficiency levels at the local conditions. These improved technologies give higher recovery rates of between 25 % to 38 % and therefore charcoal conversion efficiency and environmental conservation can be achieved through use of these improved charcoal conversion methods /technologies.

In Order to demonstrate the higher efficiency levels of improved technologies as a good alternative to the traditional kilns, studies were undertaken in Kitui, Taita Taveta, Kwale and Mbeere North through the Miti Mingi Maisha Bora (MMMB) project and a UNDP Joint UN project on Environment, Energy and Climate change. These counties are basically in the arid and semi-arid areas (ASALs) and are among the leading charcoal hotspots were charcoal is produced through unsustainable charcoal production methods. This paper aims to establish the traditional charcoal production methods used by the local communities and their efficiencies compared to improved Earth and Casamance kilns for sustainable charcoal production and barriers to adoption of the improved technologies.

Objectives of the study

The objectives of the study were to document barriers to adoption of the improved technologies by the local communities and comparatively assess the production efficiency of the traditional kilns against the improved Earth and Casamance kilns.

Methods and Materials

Study areas

The study was conducted in selected areas of Kitui (Mwingi) Embu (Mbeere North) Taita Taveta and Kwale Counties. These counties are generally ASAls with low and unreliable rainfalls ranging between 300 mm-1000 per annum. Subsistence farming and livestock production are the back bone of the economy of the inhabitants. With changing weather patterns, crop failure has become more frequent thus charcoal production becomes the alternative source of livelihoods. Charcoal is mainly produced through unsustainable charcoal conversion methods.

Data collection

A survey using a semi structured questionnaire was conducted among randomly selected 60 members from12 purposively selected Charcoal Producer Associations (CPAs) in the four study areas to establish the various types of kilns used for charcoal production and barriers to adoption of improved charcoal production technologies.

Production of charcoal using three different kilns

Charcoal was produced using three types of kilns (Traditional kiln, improved earth kiln and the Casamance kilns to compare the production efficiencies of the kilns.

Procedure

At each site wood from the same species was collected and stacked to dry to about 15-20 % moisture content. In readiness for charcoaling the wood for each kiln type was weighed and arranged as per each kiln type. Each was covered with foliage and then soil. The chimneys and air lets for the improved earth and Casamance kilns were put in place. Each kiln was replicated in three sites per study area. Data sheet was used to collect information for each type of kiln, on amount of wood (Kgs), time set (Lighting), time finished (stop carbonization), time taken to complete carbonization and amount of charcoal produced and recovery rate calculated.

Data Analysis

Data obtained was analysed using Statistical packages for social scientist (SPSS) and Excel computer packages.

Results and Discussions

Types of Kilns used and barriers to adoption of improved kilns.

Traditional 98 % and improved kilns (2 %) (Figure 1) were indicated as some of the kilns being used for charcoal production by the communities. The producers indicated that the continued preference and use of the traditional kilns was due to the fact that it's the only known technology to many, easy to use, and has been adopted from their forefathers and the skills are passed on through on job training. Apart from the low efficiency rates due to poor air control, the traditional earth kilns were indicated as easy to learn and use, can be located at the source of wood materials thus no extra cost of transporting the wood materials and can be operated by any member of the community. The improved kilns included the brick Kiln (Half orange), the metal kilns (portable and the Mekko Kilns) which most of them were observed laying idle and rusting in the open having been used not more than once.

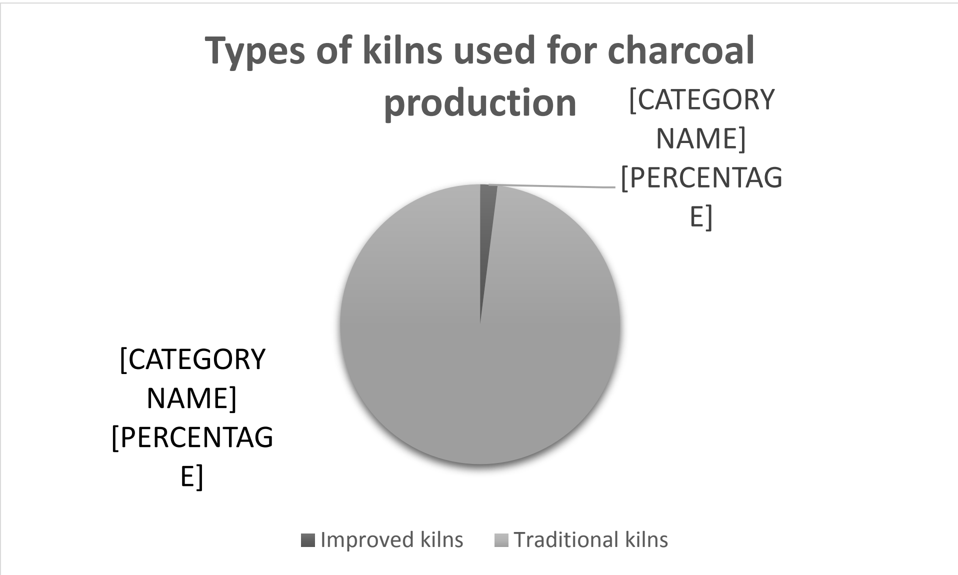

Figure 1. Types of kilns used for charcoal production.

Barriers to adoptions of the improved technologies

Lack of information and skills (88 %), high cost of the improved technologies (86 %), cultural preference 78 %) and financial constraints 72 % and high cost of improved transporting heavy kilns and wood materials (67 %) **(**Fig. 2**)** to stationery kilns were indicated some of the factors influencing adoption of improved charcoal kilns especially the metal and masonry (brick) kilns.

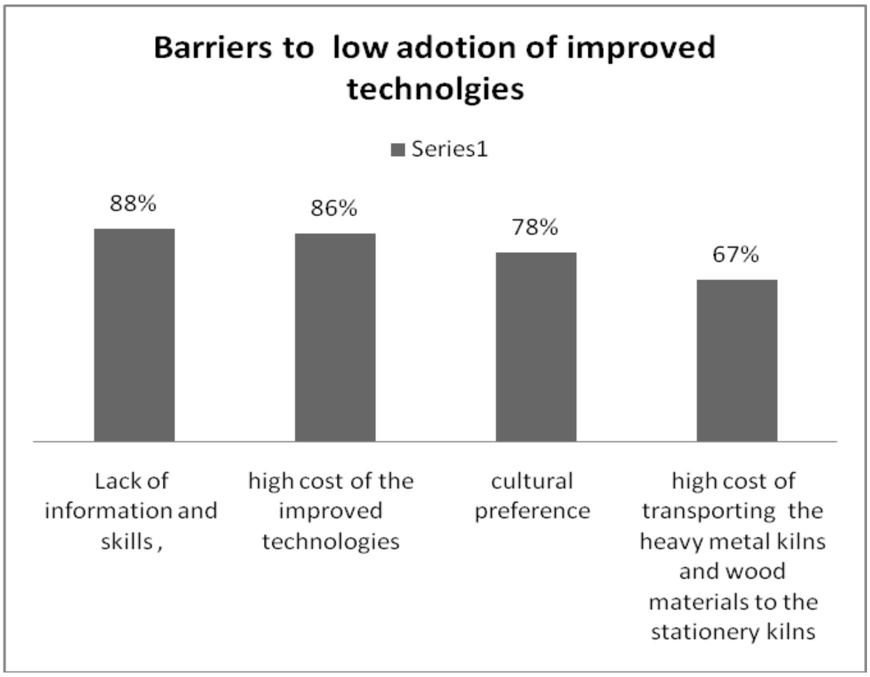

Figure 2. Barrier to adoption of the improved technologies

Production of charcoal using three different kilns

The mean charcoal production efficiency in Mwingi Sub-County from three sites namely Kyuso, Ngomeni and Mitamisyi were taken. Table 1 shows that the traditional kiln averagely took one extra day to carbonise fully compared to the improved kilns. The mean efficiency which was calculated by weight indicated that the traditional earth kiln gave 18 % while the improved earth and the Casamance kilns gave 32 % and 36 % respectively.

Table 1. Mean Charcoal Production Efficiency in Mwingi (Kyuso, Ngomeni and Mitamisyi)

Kiln Type	Amount of Wood (Kgs)	Moisture content	Mean Time Taken to Complete Carbonization (days)	Mean amount of charcoal produced (Kgs)	Mean Efficiency levels (%)
Traditional earth kiln	350	15%	4	54	18
Improved earth kiln	350	15%	3	96	32
Casamance Kiln	350	15%	3	102	36

The mean charcoal production efficiency in Taita Taveta-County from three sites namely Maungu, Mwatate and Kishushe were taken. Table 2 shows that the traditional kiln averagely took one and half extra days to carbonise fully compared to the improved kilns. The mean efficiency calculated by weight indicated that the traditional earth kiln gave 16% while the improved earth and the Casamance kilns gave 30 % and 32 % respectively. The improved kilns averagely doubled the yield of charcoal produced.

Table 2. Mean Charcoal Production Efficiency in Taita Taveta (Maungu, Mwatate and Kishushe)

Kiln Type	Amount of Wood (Kgs)	Moisture content	Mean Time Taken to Complete Carbonization (days)	Mean Amount of Charcoal Produced	Mean Efficiency levels (%)
Traditional earth	350	15%	4.5	46	16
Improved earth kiln	350	15%	3	90	30
Casamance Kiln.	350	15%	3	96	32

The mean charcoal production efficiency in Kwale County from three sites namely Lunga Lunga, Samburu and Kilubashi were taken. Table 3 shows that the traditional kiln averagely took one extra day to fully carbonise the wood compared to the improved kilns. The mean efficiency which was calculated by weight indicated that the traditional earth kiln gave 18 % while the improved earth and the Casamance kilns gave 32 % and 38 % respectively. Using the Casamance kiln more than doubled the yield of charcoal produced from using the traditional earth kiln.

Table 3. Mean Charcoal Production Efficiency in Kwale (Lunga Lunga, Samburu and Kilubashi)

Kiln Type	Amount of Wood (Kgs)	Moisture content	Mean Time Taken to Complete Carbonization (days)	Mean Amount of Charcoal Produced	Mean Efficiency levels (%)
Traditional earth	350	15%	4	63	18
Improved earth kiln	350	15%	3	112	32
Casamance Kiln	350	15%	3	133	38

The mean charcoal production efficiency in Mbeere North Sub-County from two sites namely Gathega and Kirie were taken. Table 4 shows that the traditional kiln averagely took one extra day to fully carbonise the wood compared to the improved kilns. The mean efficiency which was calculated by weight indicated that the traditional earth kiln gave 15 % while the improved earth and the Casamance kilns gave 28 % and 30 % respectively. The yield from using the Casamance kiln doubled the one from the traditional earth kiln.

Table 4. Mean Charcoal Production Efficiency in Mbeere North (Gathega and Kirie CPAs)

Kiln Type	Amount of Wood (Kgs)	Moisture content	Time Taken to Complete Carbonization (days))	Amount of Charcoal Produced	Mean Efficiency levels (%)
Traditional earth	350	15%	5	52.5	15
Improved earth	350	15%	4	98	28
Casamance Kiln	350	15%	4	105	30

Results from the four study areas indicate improved earth and Casamance kilns have a higher efficiency rates than the traditional kilns even when operated under same management and conditions as indicated in Figure 3.

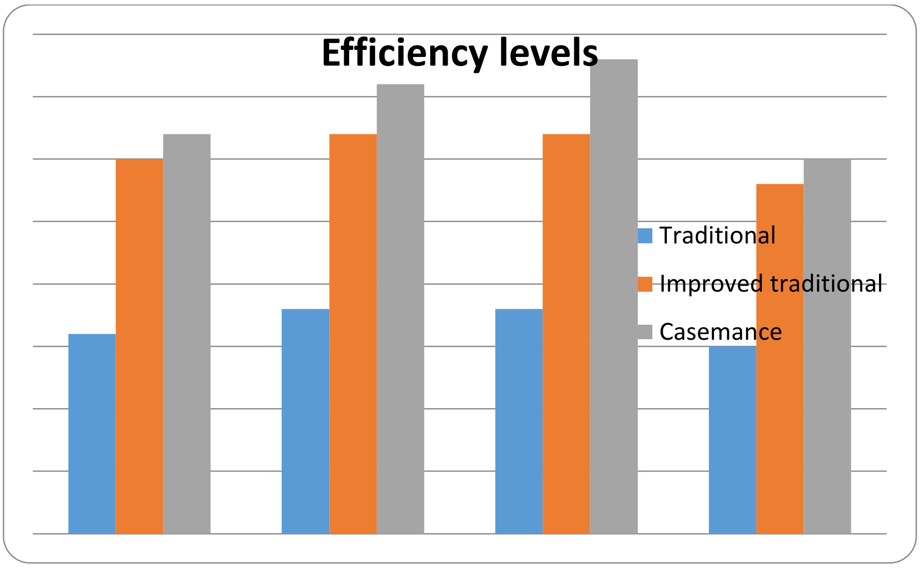

Figure 3. Efficiency levels of the three types of kilns in the four study areas.

Even though similar amount of wood materials was used in all study areas, the differences in production capacities of the three types of kilns within and amongst the four study areas could have also been influenced by the types of tree species used, the skills of the producer's and to some extend the weather conditions. In Mbeere north, the windy and rain conditions and use of poor species such as *Delonix elata* could be attributed to the high number of days taken by all kiln types to carbonize, while in Taita Taveta, lack of big mature trees, thus use of juvenile materials could be attributed to the lower production results.

In Kwale and Mwingi which produced the first and second highest mean efficiency levels, more mature wood materials of the preferred trees species was availed for carbonization by the community. In Mwingi, wood materials from species known to produce quality charcoal such as *Acacia tortilis, Acacia mellifera* and *Acacia senegal var keniensis* were availed while in Kwale species such as *Terminalia spinosa, Acacia mellifera, Combretum molle* and *Acacia horrida* are still being exploited for charcoal production.

Conclusions and Recommendations

The study concludes that to improve on the sustainability of the charcoal sector, there is need for increased awareness on use of improved charcoal production kilns such as the improved earth and Casamance kilns for efficient charcoal production to meet the ever increasing demand for charcoal products. Compared to other types of kilns, improved traditional and Casamance kilns only requires accessories such as air inlets and chimneys which are available and affordable to the charcoal producers. Drying of wood materials and proper stacking of the wood will ensure higher efficiency levels. This will also reduce the continued cultural preference of traditional kilns, leading to improved livelihood and environmental conservation through reduced selective harvesting of preferred tree species. The study recommends increased dissemination of information and skills on the improved earth and Casamance kilns for improved charcoal production capacities and environmental conservation. There is also need for technology developers to borrow the positive aspects of traditional technologies in development of improved technologies and to increase participation of all charcoal producers in order to gain skills and information on technologies which promote sustainable charcoal production. There is need also for subsidies and tax incentives by the government for reduced prices of improved technologies for increased adoption.

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Optimization of Piperine Extraction from *Piper nigrum* using Different Solvents for Bedbug Management

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Abstract

Insecticides are agents of chemical or biological origin that control insects. Control may result in killing the insects or preventing them from engaging in activities deemed destructive. Use of natural products as insecticides is beneficial since the natural products extracts will still provide ecosystem balance unlike the use of synthetic insecticides. Insecticides from plants are preferred because synthetic ones have negative environmental impact and insects develop resistance against target insecticides. Herein, optimal conditions for piperine extraction and its efficacy as an insecticide are reported. The extract is non-toxic to humans with low risk of poisoning. Black pepper (*Piper nigrum* L.) and all the reagents were obtained from commercial sources and used without further purification. Piperine was extracted using soxhlet extraction method and characterised. Ethanol gave the highest yield of piperine compared to dichloromethane. Due to low water-solubility of piperine, different solvent mixtures were used to improve solubility. Toxicity against bedbugs (*Cimex lectularius*) was carried out and the optimum concentration determined to be 1.3 g/L of piperine in a mixture of ethanol/water (1:4). Piperine was found to kill mature bedbugs faster than the younger bugs. The extract was also 100 % effective in inhibiting bedbug eggs from hatching while 83.4 % the unsprayed eggs hatched within seven days. Piperine can, therefore, serve as an insecticide against bedbugs since it is effective on all developmental stages of the bugs.

Key words: Bed bug, inhibit, insecticide, piperine, toxicity.

Introduction

Bedbugs (*Cimex lectularius*) are small, oval, brownish insects that live on the blood of animals or humans. Adult bedbugs have flat bodies, and are about the size of an apple seed. After feeding, however, their bodies swell and have a reddish color (Miller *et al.*, 2013). Young bedbugs are smaller, whitish-yellow in color; nearly invisible to naked eye if not fed. Although insecticides have been formulated to assist in the control of bedbugs, the insects have continuously developed resistance to some of the synthetic insecticides used and these insecticides are considered to be comparatively high environmental pollutants (Dang *et al.*, 2017). For example, due to heavy bedbug infestations in army barracks in 1942, Dichlorodiphenyltrichloroethane (DDT) was heavily used to control bedbugs (Potter, 2011). However, the DDT failure against *C. lectularius* was first reported in 1947 at a Naval Receiving Station in Pearl Harbor, Hawaii (Johnson, 1948). By the 1950s, bed bug resistance to DDT was widespread (Busvine, 1958; WHO, 1992 and Zhu, 2008). This has made the insects to spread from bedrooms to workplaces and even to the travel industry including road transport and aviation.

Black pepper (*Piper nigrum* L.) is an evergreen climbing plant that originated in the Western Ghats of India and subsequently spread to other countries (Thangaselvabal *et al.*, 2008). It is commonly grown in many tropical regions like Brazil, Indonesia and India at temperatures ranging between 15 and 40 °C. The vine does well under humid conditions at altitudes of about 1,500 m above sea level and rainfall of about 180 cm per year distributed throughout the year. The fruits of *Piper nigrum* are used to produce white and green peppers. To get black pepper, the unripe peppercorns are sun-dried causing the outer skin to turn black and wrinkle. For white pepper, the ripe berries, having turned red, are soaked, then the outer covering is rubbed off (Purseglove *et al.*, 1981). Commonly, fruits of *P. nigrum* are used as spices as well as medicine (Leung, 1980). This spice, with its characteristic pungency and flavor (Ahmad *et al.*, 2012), is used as an ingredient in many food preparations.

The fruits of *P. nigrum* contain five different constituents which include; piperine alkaloid, pungent resin, volatile oil, piperidine and starch. Of all these alkaloids, literature review shows that piperine has the highest percentage in concentration (Mukherjee, 2008 and Kokate *et al.*, 2010). Piperine, (2*E*,4*E*)-5-(benzo[*d*][1,3]dioxol-6-yl)-1-(piperidin-1-yl)penta-2,4-dien-1-one, is responsible for the bitter taste of *P. nigrum*. Piperine has the methylenedioxyphenyl group which is responsible for killing of insects rather than repelling them (Trease, 1983 and Duke, 2010). These effects, necessitated the extraction of piperine from the fruits of *P. nigrum* in order to investigate its insecticidal properties against bedbugs.

Piperine (figure 1) has low solubility in water, but ethanol and other organic solvent are suitable for dissolving this substance. It is reported in literature that chloroform is the best solvent for extraction of piperine but this solvent is classified as one of the carcinogens (Tripathi, 2017). This property formed the basis of piperine extraction from *P. nigrum* using ethanol (which is non-toxic to humans) in comparison to dichloromethane (an alternative to chloroform) in order to establish the solvent that gives better yield. Thereafter, an evaluation of piperine's suitability in the control of bedbugs was carried out.

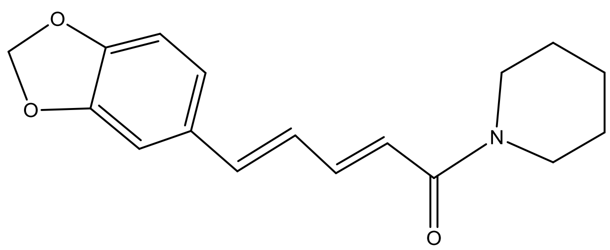

Figure 1. Structure of piperine

Materials and Methods

All solvents, reagents and black pepper were obtained from commercial sources and used without further purification. Bedbugs were obtained from hostels and some from highly bedbug infested homes. Fine powdered black pepper (10 g) was placed in a soxhlet thimble and then extracted using 100 mL of ethanol for 240 minutes. The solution obtained in the round bottom flask was then concentrated using a water bath while keeping the water bath at 90 °C during the concentration process. Exactly 10 mL 10% of alcoholic potassium hydroxide was added to the residue with continuous stirring. The insoluble residue was then filtered and alcoholic solution concentrated at room temperature. Some crystals were formed at the sides of round bottom flask, which were dissolved in hexane: ethanol mixture and the solution formed transferred into a vial and left to concentrate at room temperature to crystallize out piperine.

Experimental extraction of piperine

Equal masses of black pepper powder (10 g) were subjected to same extraction apparatus and similar duration of time to ensure uniformity in extraction procedure for comparison purposes. The experiments were done in triplicate. The ground pepper powder was placed in a soxhlet thimble and then extracted with dichloromethane (DCM) in a round bottom flask as described by Shingate *et al*., (2013). The procedure was repeated using ethanol as the extraction solvent. Characterization of piperine was done according to literature procedure (Saha *et al.*, 2013).

Bioassay

Toxicity of piperine was tested using bedbugs. Bedbugs were sourced from hostels within Dedan Kimathi University of Technology neighborhood and stored in a well aerated transparent vial with a rug and covered with a cap. Bedbugs were kept at room temperature and all the tests were done under similar laboratory conditions to avoid sudden external environmental change (Romero *et al.*, 2009). The vial was kept at 25 °C in an open shelf to avoid suffocating them. The bedbugs were classified by length differences; mature bedbugs were classified as those with length above 2 mm, while young bedbugs those with length less than 2 mm. Piperine was first dissolved in ethanol and further dissolved in water to obtain light-yellow solutions with different concentrations of 1.3, 1.5, 1.8, 2.1 and 2.5 g/L. Efficacy tests were carried out in triplicates at these concentrations for both mature and young bedbugs in vials. To each test vial, a piece of cloth was first placed to simulate the practical conditions of application and avoid drowning the specimen. The prepared solutions were then sprayed to the specimen with the help of a spray bottle. Response time (in minutes) for both the specimen to die and piperine to precipitate were determined for the different concentrations in water/ethanol mixture (2:1). This was repeated for (4:1) water/ethanol mixture. Controls were kept for all replicate experiments.

Test on bedbug eggs

On collecting the bedbugs for the purpose of this research, the specimens were kept in a vial with a rug. After a week, eggs were observed on the rug. Carefully, the bedbugs were separated from the rug. The rug was then divided into two. The number of eggs on each rug was recorded. The eggs were placed in separate vials for the purpose of determining their chances of hatching. One was sprayed with piperine dissolved in water/ethanol mixture (4:1) at optimum concentration determined from the bioassay experiments while the other one remained unsprayed as a control. Two vials containing bedbug eggs were kept under similar conditions.

Results and Discussion

Extraction of Piperine

There was a difference in piperine yield and extraction time for DCM and ethanol solvents. Ethanol took three to four hours for the solvent to clear compared to DCM which took two hours. The time difference could be attributed to the differences in boiling points of the solvents (39.6 and 78.4 °C for DCM and ethanol respectively) since DCM requires less energy to complete one cycle than ethanol. For DCM, after the first four empties, the solvent in the thimble turned clear implying no piperine was left in the sample. The difference in cycles is attributed to piperine solubility in different solvents. Piperine is slightly soluble in water (40 mg/L, or 1 g/25 L (18 °C) and more so in alcohol (1 g/15 mL), ether (1 g/36 mL) or chloroform (1 g/1.7 mL) (Harwood, 1989).

The extraction process for piperine using ethanol yielded 1.010 g (10.1 %, w/w) while the extraction using DCM yielded 0.074 g (7.42 %, w/w) of piperine from the dried black pepper powder. This outcome was much desired as there are some healthy side effects associated with prolonged and long exposure to DCM (Rioux, 1988). Although DCM is a preferred substitute for chloroform, recent studies have shown that length exposure to this solvent has similar effect to that of chloroform (Schlosser *et al.*, 2015). The authors have pointed to the possibility of DCM being carcinogenic to humans based on animal studies that resulted in carcinogenicity of the liver and lungs in mice. Ethanol gave a better yield despite requiring more energy i.e. longer time to extract piperine from the powdered *P. nigrum* fruits. Considering the health implications of DCM, ethanol will be a solvent of choice for this purpose since moderate exposure to ethanol is not harmful to humans (Ahmed, 1995).

Bioassay

Piperine solubility in water was a major hindrance in this study and therefore a better solvent system to dissolve crystals was required. Due to this challenge, a specific mass of piperine was weighed first then dissolved in a known volume of ethanol. Piperine fully dissolved in ethanol. When a known volume of water was added to the mixture, piperine crashed out of solution. Consequently, piperine was first dissolved in ethanol and then added drop-wise into water with vigorous stirring to obtain concentrations of 1.3, 1.5, 1.8, 2.1 and 2.5 g/L in in water/ethanol mixtures of (4:1) and (2:1) respectively. Thus, prepared solutions were used within five days of preparation. Efficacy test was carried out on both mature and young bedbugs. The results obtained are presented in Figures 2 and 3.

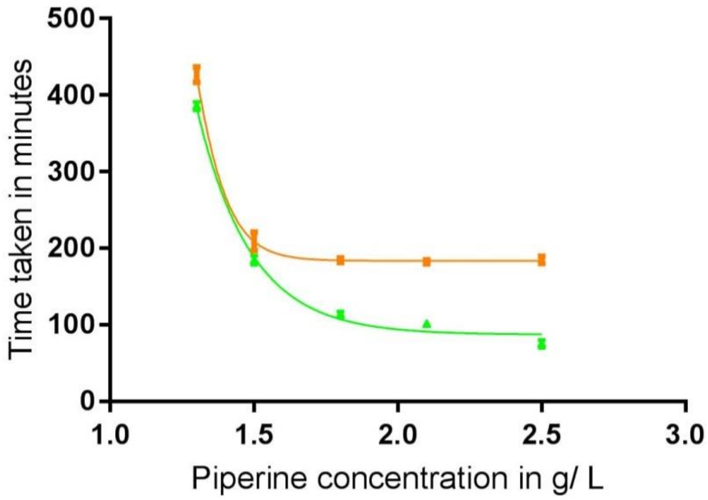

Figure 2. Time taken by young bedbugs (orange) and mature bedbugs (green) to die in different piperine concentrations in ethanol/water (1:4) mixture

It was clear from the bioassay results that mature bedbugs take a relatively shorter time to die as compared to young ones when sprayed with the same concentration of the solution. For example, at piperine concentration of 2.0 g/L in ethanol/water (1:4) mixture, mature bedbugs died after 100 minutes while young bedbugs died after 200 minutes (Figure 3). However, as concentration reduced, the time taken by both groups narrowed to a common time. At concentration 1.4 g/L, both mature and young bedbugs took approximately 300-minute post-exposure to die. This was taken to be the optimum dosage for the extract.

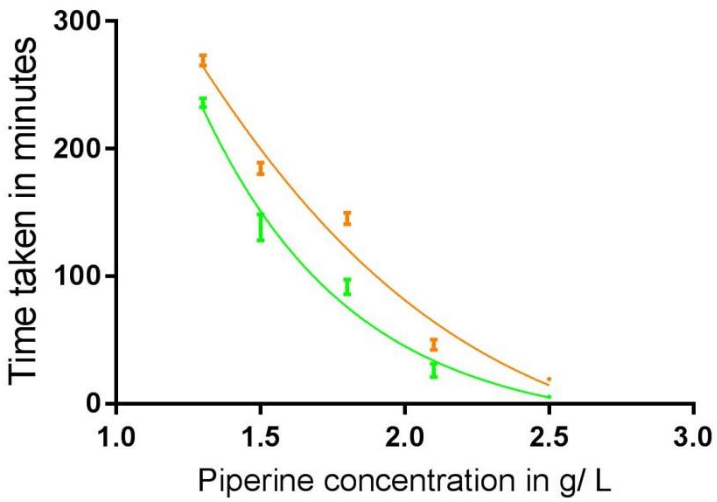

Figure 3. Time taken by young bedbugs (orange) and mature bedbugs (green) to die in different piperine concentrations in ethanol/water (1:2) mixture

Similarly, the bioassay results for piperine in ethanol/water (1:2) mixture for both mature and young bedbugs followed a comparable trend (Figure 3). For example, at piperine concentration of 2.0 g/L, it took mature bedbugs 50 minutes on average to die while young bedbugs took approximately 100 minutes. The results indicate that increasing the amount of ethanol significantly reduces the time it takes for piperine to kill the bedbugs. This can be explained by preliminary tests of pure ethanol on the bedbugs. An average of 3.33 minutes for mature bedbugs and 9.33 minutes for young bedbugs were recorded as time taken to die post-exposure to pure ethanol, implying that ethanol can be used as an insecticide by itself. However, economic factors were taken into consideration when deciding on the best solvent system for this purpose. Minimum amount of ethanol and least possible amount of piperine were used to determine the optimum concentration. In addition, ethanol is flammable and therefore cannot be considered as a safe option for bedbug control.

From the bioassay results above, using ethanol/water (1:2) was not economical due to high amount of ethanol required which can make the insecticide expensive. Therefore, a concentration of 1.3 g/ L of piperine in ethanol/water (1:4) was considered to be the optimum concentration for an insecticide formulation. Despite the fact that it takes longer time (≈ 400 minutes) to kill the bugs, the final result is satisfactory compared to synthetic insecticides such as Doom andPromax that work within days but have no ability to destroy the eggs, piperine extract can be an insecticide of choice in the fight against bedbugs.

It is also worthy to note that control specimens for this study survived for extended periods of time. The mature control bedbugs stayed as long as 22 days while young ones survived up to 56 days without any supplements. This observation matched the earlier one which indicated that mature bedbugs died faster than the young ones on spraying them with insecticides.

Test on bedbug eggs

Out of twelve eggs that were in the vial sprayed with the piperine solution, none hatched. This indicated the ability of the insecticide to inhibit hatching of the bedbug eggs. This may have been caused by piperine and ethanol which acting as a thin film on the egg shell and therefore disrupting the hatching. The sprayed eggs turned from white to yellow lastly darkening in color which was an assurance that hatching would not take place. Nonetheless, of the seventeen eggs in the unsprayed vial, fourteen eggs hatched after seven days while three did not even after twenty days. This represents a viability rate of 83.4 %. This is comparable to the data that was obtained (Miller, 2013).

Conclusion

Piperine was extracted from black pepper using DCM and ethanol in 7.42 % and 10.1 % yields respectively. Piperine in water/ethanol (4:1) solvent mixture has potential to be used as an insecticide against bedbugs, although it may work better in a suitable surfactant or solvent system. In addition, young bedbugs take relatively longer time to die in comparison to mature bedbugs under similar conditions. This implies that there are differences in the mode of action of insecticide at different stages of their life cycle. On the other hand, the ability of piperine to inhibit the hatching of bedbug eggs is of significance since a single spray has the potential eliminate an entire generation of the bedbugs - it is effective against all stages. However, further research should be carried out to determine better solvents for piperine to fully work as an insecticide. Research should also target the possibility of including piperine in soap formulations that can be used for laundry work as a way of destroying bedbug eggs, larvae or mature bedbugs. Further work to establish the mode of action of piperine on bedbugs is also recommended.

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Guava Preferences amongst Children in Western Kenya

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Abstract

Guava (*Psidium guajava*) is important in the livelihoods of rural communities in Kenya. Although this fruit is used as source of food and income, research and development initiatives to create a favourable framework for its domestication and commercialization is limited. Moreover, the existing information is scattered and its impact on improvement of guava is insufficient. Thorough knowledge of this fruit species is a prerequisite for effective improvement. The objectives of this study were to document preferences of consumption of guava types amongst primary school students and to recommend research direction for this crop. A study was conducted to quantify guava preferences in Western Kenya amongst primary school pupils. A questionnaire was pre-tested and administered randomly to standard eight pupils from six primary schools. Descriptive statistics (frequencies, means, percentages, totals) were used to describe quantitative data from the sensory analysis. Comparison of guava consumption and sensory analysis data between male and female pupils was done using Pearson chi-square test for categorical variables. The most liked guava taste type was the "sweet type" (88.3 %); followed by "salty" (56.9 %) and the bitter/sour types (30.4 %). Most (39 % and 31 %) children preferred whole fruit with yellow or green skin, respectively, 8 % and 4% liked the rind only and 11 % and 6 % ate only the central core with seed of pink or white fleshed fruit, respectively. There were significant differences for gender preference for flesh colour. This data will inform breeding programmes on the type of guava to develop targeting increased utilization by children.

Key words: Guava, *Psidium guajava* L, sensory analysis

Introduction

Traditional knowledge on indigenous or local agrobiodiversity is rapidly declining (Sogbohossou *et al.*, 2015), and with increasing globalization in food culture, diets as well as farms have become less diverse as monoculture is encouraged. Studies show that dietary diversity is associated with improved nutrition (Anon, 2012, Ruel *et al.*, 2005). Effective food-based dietary strategies are one of the most sustainable nutritional interventions, as long as nutritionally adequate diets based on local foods can be successfully identified and promoted (Ferguson *et al.*, 2004). Documenting local knowledge on agricultural biodiversity and reinforcing it with scientific evidence could contribute towards conserving and promoting utilization of nutritious foods. Also, since local food plant species are adapted to local environmental conditions, they play additional roles in stabilizing yields and access to food, improving pest and disease management, delivering a range of other vital ecosystem services (e.g. pollination), managing risk, and building system and household resilience to shocks. Kenya Agricultural & Livestock Research Organization (KALRO) is spearheading the implementation of a project on mainstreaming biodiversity for food and nutrition in Kenya globally coordinated by Bioversity International. The organization is collaborating with Jomo Kenyatta University of Agriculture and Technology, Kenyatta University, Ministries of Agriculture (policy unit) and Health (nutrition unit) and the National Museums of Kenya. This project has generated, documented and created widespread awareness on the beneficial nutrients which are in underutilized fruits.

In recognition of the need to increase utilization of underutilized fruit species and further revitalize and harness edible landscapes in Kenya, this study was implanted to document consumption of guava (*Psidium guajava* L) by children in Western Kenya. This is the first of interrelated studies with objectives that will inform collection, conservation and promote consumption of underutilized fruits in Kenya with proven nutritive benefits for human nutrition and health. These studies will harness edible plants for diet diversity and improved nutrition, contribute towards the conservation of underutilized fruits, strengthen endangered food systems in Kenya. It will also contribute to conserving agrobiodiversity and cultural practices for enhanced local livelihoods, integration of youth, farmers and researcher knowledge by promoting utilization of underutilized species.

Maundu *et al.* (1999) has documented about 400 indigenous fruit species in Kenya. Although this country has a wide diversity of guava phenotypes, a few are cultivated by farmers for utilization or commercialization. This is not unique to guava in Kenya but also has global dimensions with several species. For example, from approximately 350,000 plant species globally, 80,000 are edible, about 150 are commonly cultivated, and around 30 species constitute 90 % of calorific intake. Data capture on cultivation of underutilized fruit species by Horticulture Crops Development Authority (now Horticulture Crops Directorate) commenced early in 2000s. There was a rapid expansion of area under guava from 2005 and 2009 from 251 to 1,099 ha. Production increased from 1,255 tons to 6,010 tons and the value increased from KES 18,825,000 to KES 39,972,000, respectively (GoK, 2010). Recent data capture for 2016 ranks guava as the 12th most important fruit in Kenya where area under cultivation is 1,806 ha producing 9,800 tons valued at KES 57,737,125. There are discrepancies in data capture whereby statistics for 2015 show area under production as 2,687 ha producing 8,713 tons valued at KES 71,507,784 (AFA, 2015, AFA, 2017). The fact is that Kenya has observed increased production of guava demonstrating the importance of this crop in rural livelihoods.

Guava is an important crop for rural communities because of its environmental resilience. This underutilized fruit is particularly important in regions where the major farming enterprises are sugarcane or maize production. Some of counties in these regions record the highest rates of under-nutrition e.g. Busia and Bungoma Counties (Matanda *et al.*, 2014, Njogu *et al.*, 2015). In periods of drought or the dry season, various indigenous or underutilized fruits such as guava are consumed for survival. Although guava has been used as a source of food and income, research and development initiatives to create a favourable framework for its domestication and commercialization are limited. Existing information on guava is scattered, unreliable and inconsistent making it difficult to justify development of an improvement programme (Anastacia *et al.*, 2010). Thorough knowledge of this fruit species is a prerequisite for effective improvement. Reports by Kidaha *et al.* (2015) and Gatambia *et al.* (2010) show that guava in Kenya has a wide phenotypic and genetic diversity. The objectives of this study were to document preferences of consumption of guava types amongst primary school pupils and to recommend the research direction for this crop. The importance of biodiversity in schools at an early age is key to show that "children favored foods" such as guava, cape gooseberry, avocado, termites and variety of other underutilized products contribute to physical and mental development (Wasilwa *et al.*, 2015).

Materials and Methods

To determine preference of guava fruit consumption, students from six schools located in two sub-counties (Tongaren Sub-County and Bungoma North Sub-County) in Bungoma County were considered in this study. They included Maresi FYM (Friends Yearly Meeting) Mission, Matisi PAG (Pentecostal Assembly of God), Kananachi FYM, Chuma PAG, Matisi PAG, and Mitua FYM. The primary schools were representative of typical schools in Western Kenya. Because of variations in age, a sample of 200 pupils was used to cover all ages ranging from 12 to 22 years old. Data was collected using a semi-structured questionnaire administered to standard eight pupils (respondents). The questionnaire was prepared and pre-tested before being administered. Data analysis involved reviewing and grouping the collected data under specific themes.

Morphology and colour of guava fruit and flesh

A pictogram of types of guava found in Western Kenya was presented to primary school children. The children were requested to select all the types (8 types were presented) of guavas they preferred based on shape (round, oval, oblong, and nipple) and fruit skin colour. The guava descriptors for fruit skin colour were previously described by Rodríguez-Medina *et al.* (2010). A second pictogram with 8 images displayed the colour of fruit flesh ranging from white, cream, yellow, light pink, and dark pink (Rodríguez-Medina *et al.*, 2010, Rajan *et al.*, 2011). The respondents were instructed to choose all the types they preferred to consume from the pictures taken of mature fruit.

Size of guava fruit

Morphological characteristics of guava varieties and landraces growing in Western Kenya are diverse as previously stated by Kidaha *et al.*, 2015. These germplasm produce fruit of a wide range of sizes. A question on the size of fruit preference was presented by using an illustration of big (> 8 cm), medium (>5 to <7 cm) and small fruit (<4cm).

Sensory evaluation of guava

A 5-point hedonic scale was used for sensory evaluation of guava taste, i.e. 1=dislike very much; 2=dislike; 3=fair (neither like nor dislike); 4=like; 5=like very much (Fig. 1). To administer this question, the children were asked to rate their preference to three types of guava including the sweet, "salty" and "bitter" or sour types. To make this easily understood, the terminologies to describe these guavas in the community were used i.e. the sweet type are referred to as *kasukari*, the salty type as *khachumbi* and the bitter or sour types as *khalulu*. The pupils ticked the face that related to their preference using the five-point scale described above and demonstrated in Fig. 1 below.

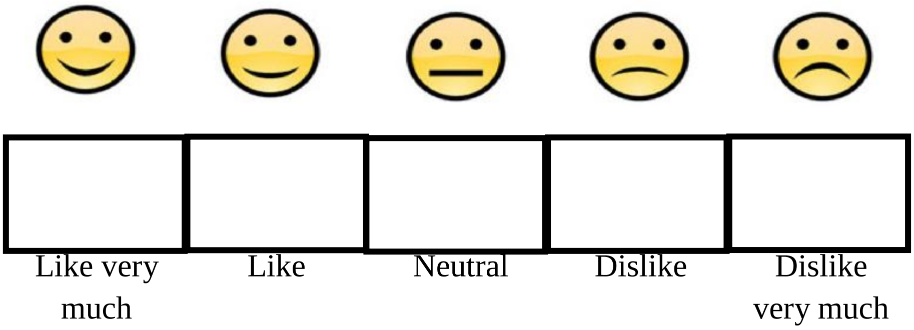


Figure 1. Pictorial of the 5-point hedonic scale used for sensory evaluation of guava taste in Bungoma, County

Consumption of guava

It was randomly observed that in Western Kenya, there are varied consumption patterns of guava. They are three types of consumption patterns i.e. those children that consume the entire fruit; those that consume only the rind (outer cover of fruit) and on the seed capsule. A pictogram showing the two common types of guava flesh colour (pink and white) was used to confirm preference.

Data analysis

Descriptive statistics (frequencies, means, percentages and totals) were used to quantify the data from the sensory analysis—continuous and categorical variables being reported as mean ± standard errors and percent (%), respectively. Comparison of guava consumption and sensory analysis data between male and female pupils was done using Pearson chi-square test for continuous and categorical variables, respectively. All analyses were done in SPSS Statistics Version 20 (IBM Corporation, SPSS Statistics Release 20.0.0: USA) and MS-Excel 2013 for Windows (Microsoft Corporation, USA). A probability of $p \leq 0.05$ was considered significant for all statistical analyses. The results are presented using tables and graphs.

Results

Study Sites and interviewed respondents

Although 200 respondents were interviewed from Tongaren and Bungoma North sub-counties only data from 197 respondents representing 6 out of 10 schools and a pilot farm for guava Tete Farm in Tongaren Sub-County was analysed in this study as shown in (Table 1 and 2).

Table 1. Number of respondents in Bungoma County

Sub-County	Number of Participants		
	Male	**Female**	**Total**
Tongaren	43	52	95
Bungoma North	57	45	102
Total	**100**	**97**	**197**

Table 2. Study sites and interviewed respondents

Sub-County	School	Male	Female	Total No. of respondents
Tongaren	Maresi FYM	14	26	40
	Matisi PAG	12	11	23
	Kanananchi	18	13	31
	Tete Farm[1]	1	0	1
	Total	**45**	**50**	**95**
Bungoma North	Chuma PAG	19	22	41
	Matisi PAG	16	4	20
	Mitua FYM	22	19	41
	Total	**57**	**45**	**102**

FYM = Friends Yearly Meeting PAG = Pentecostal Assembly of God 1= Pilot guava farm in Bungoma County

Age of respondents

The age of the pupils ranged from 11 to 22 years with a mean of 15.6±0.5 years. There was one respondent, aged 82 years from Tete Farm in Tongaren Sub-County that represents the guava pilot farm in the region (Table 3).

Table 3. Age of respondents

Sub-County	Age Years		
	Minimum	Maximum	Mean ± SE
Tongaren (n=95)	12	82[2]	17.3±1.1
Bungoma North (n=102)	11	22	14.1±0.2
Overall sample (n=197)	11	82	15.6±0.5

SE = Standard error of mean 2: This farmer was included as pilot for a subsequent study

Production of Guava

To be able to determine the source of part of the fruit consumed by the respondents, a question on number of trees at their resident farm or home was presented. Majority (77.2 %) of respondents (n=197) had guava trees on their farms or home compound. Over half of the respondents (57.9 %) had 1-5 guava trees on their farms, and only 5 % of the respondents had more than 20 guava trees in their farms (Table 4).

Table 4. Number of guava trees in the farm or compound located in Bungoma County

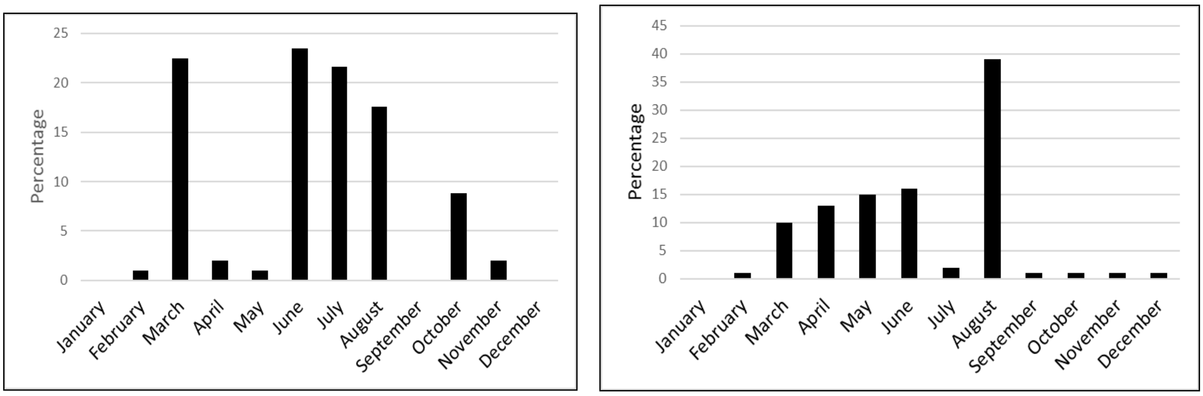
No. of guava trees	Bungoma North (N= 102)		Tongaren (N=95)		Overall Sample (N=197)	
	n	**%**	**n**	**%**	**n**	**%**
No trees	17	16.7	18	18.9	35	17.8
1-5	54	52.9	60	63.2	114	57.9
6-10	18	17.6	4	4.2	22	11.2
11-20	7	6.9	9	9.5	16	8.1
>20	6	5.9	4	4.2	10	5.1
Total	**102**	**100**	**95**	**100**	**197**	**100**

N indicates total sample size per site *n indicates number of pupils that responded*

Guava Consumption

Majority of the respondents in Bungoma County (99.0 %) reported that they liked eating guava fruit. There was however no significant difference (p=0.983) between male and female pupils regarding their liking of guava consumption (Table. 8).

The respondents report that ripe guavas are found on trees mostly in the months of March to August Fig 2a and 2b, with fluctuations in-between but the month of August having the highest number of ripe guavas on trees (Fig. 3). The months of September to February had the lowest number of ripe guava on trees, with the month of January having no ripe guava on trees (Fig. 3).



A B

Figure 2. Months when ripe guavas are found on trees in (A) Bungoma North Sub-County and (B) Tongaren Sub-County of Bungoma County

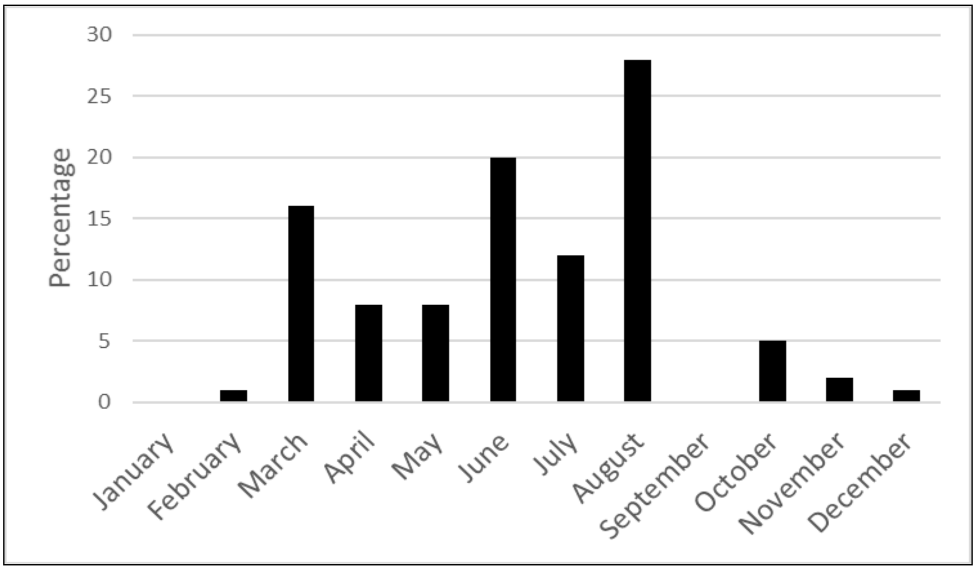
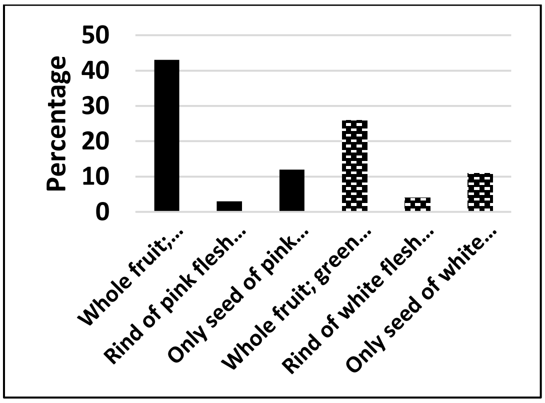


Figure 3. Months guava fruits are available on farms/ homes of 197 primary school students in Tongaren and Bungoma North Sub-Counties of Bungoma County

The most preferred form of consumption of guava was in the form of whole fruit with yellow skin being the most preferred by the pupils compared to the whole fruit with green skin (Figs. 4 and 5). The least preferred form of consumption of guava was the rind of the white flesh (outer cover) and only the seed of the white flesh pulp, respectively (Fig. 5). There was no significant difference (p > 0.05) in the preferred forms of consumption of guava between male and female pupils; apart from the whole fruit with green skin (p=0.017) (Table 8).



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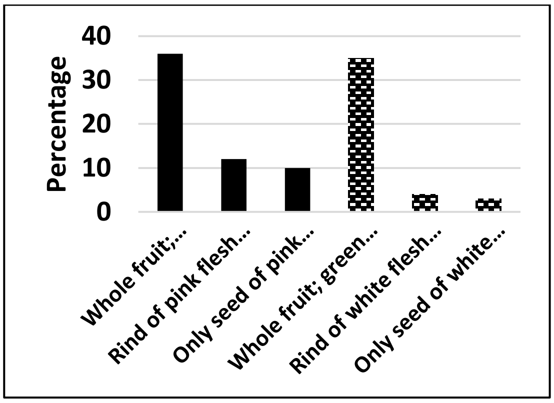

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Figure 4. Guava fruit eating preference of primary school pupils in (A) Bungoma North and (B) Tongaren Sub-Counties of Bungoma County

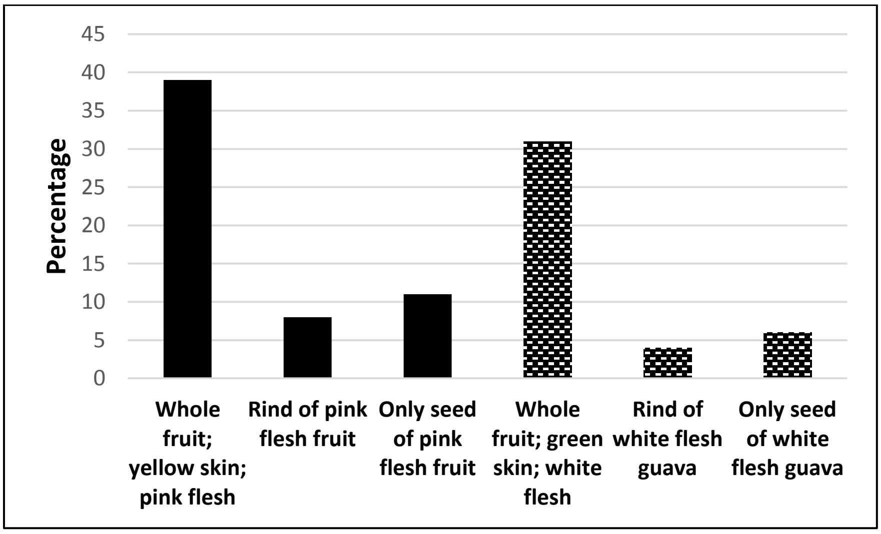
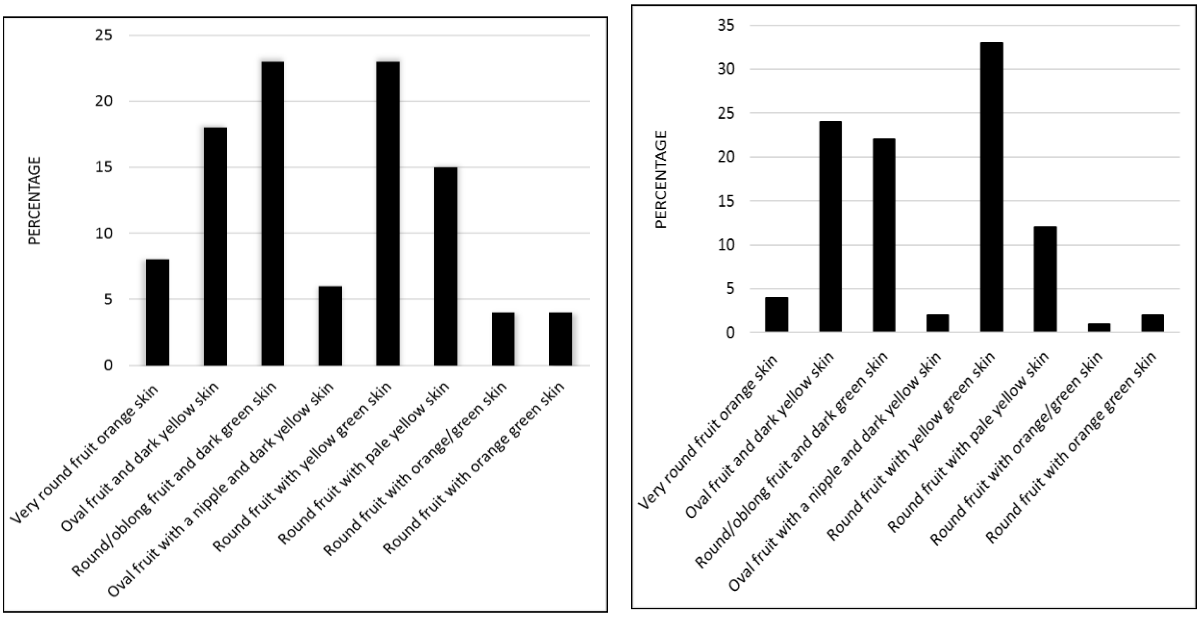


Figure 5. Guava fruit eating preference of primary school pupils in Bungoma County

Type of Guava – Shape and Skin Colour

Shape and skin colour were most used to select guava with oval yellow/green fruit being the most liked by pupils. Second was the oval green fruit and lastly oval bright yellow fruit. Round shape and orange green skin colour were the least liked (Fig. 7). There was no significant difference in preference of guava shape and skin colour between male and female pupils (p>0.05) (Table 8).



A B

Figure 6. Respondent preference of shape and skin colour of guava fruit (**A)** Bungoma North Sub-County and (**B)** Tongaren Sub-County of Bungoma County

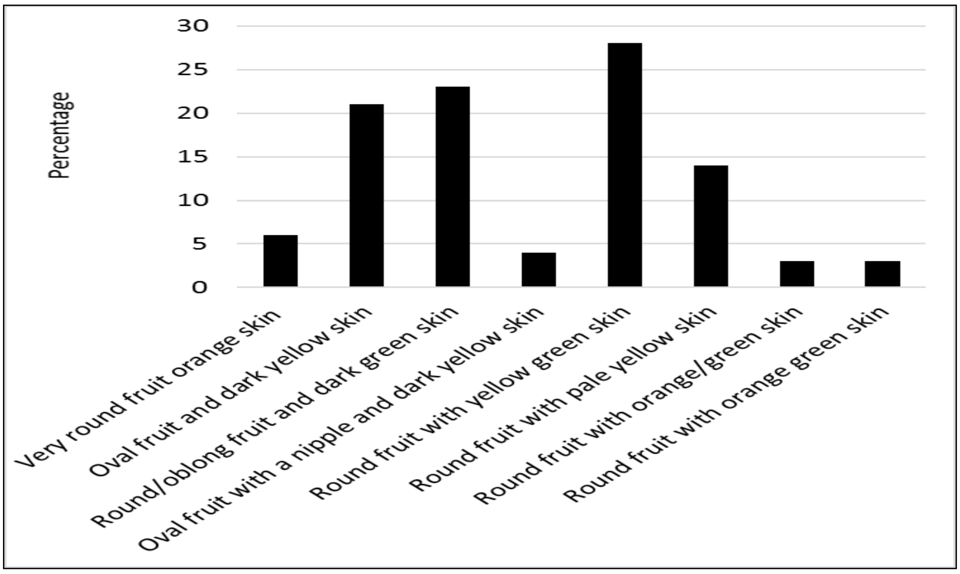


Figure 7. Respondent liking or preference of type and skin colour of guava fruit in Bungoma County

Colour of Flesh

Overall, the dark pink flesh colour was the most liked/preferred by the pupils, followed by pink flesh colour and pale pink flesh colour. Flesh colour code rosy pink was the least preferred, followed by cream flesh colour (Table 5). There was significant difference in preference of guava flesh colour between male and female students for some flesh colour codes—i.e. rosy pink flesh colour (p=0.001), dark pink flesh colour (p=0.0200), light pink flesh colour (p=0.015), cream flesh colour (p=0.022) (*see* also Table 8).

Table 5. Preference of flesh colour of guava by primary pupils in Bungoma County

Preferred guava flesh colour	Bungoma North (N= 102)		Tongaren (N=95)		Overall Sample (N=197)	
	n	%	n	%	n	%
White	30	29.4	24	25.3	54	27.4
Cream	14	13.7	6	6.3	20	10.2
Pale pink	48	47.1	26	27.4	74	37.6
Light pink	15	14.7	11	11.6	26	13.2
Pink	58	56.9	55	57.9	113	57.4
Dark pink	83	81.4	72	75.8	155	78.7
Orange pink	20	19.6	10	10.5	30	15.2
Rosy Pink	11	10.8	7	7.4	18	9.1

N indicates total sample size per site n indicates number of pupils that responded

Size of Guava Fruit

Medium size guava was the most preferred by most of the pupils (Fig. 8). There was significant difference between male and female pupils regarding preference for big size (p=0.009) and medium size guava (p=0.032) (Table 8). Small size guava was preferred by less than 5 % of the pupils —there being no significant difference in preference between male and female pupils (p=0.965) (Table 8).

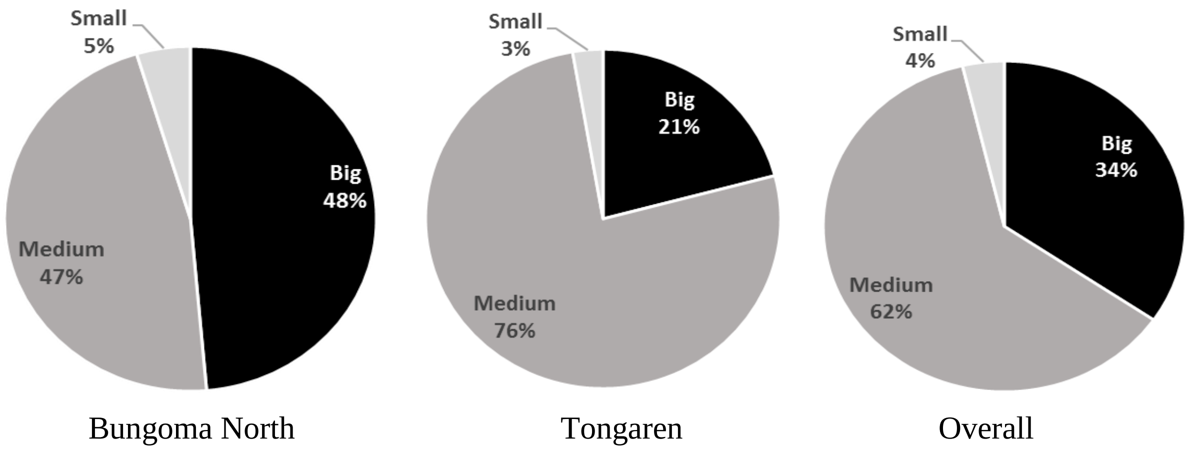


Figure 8. Preference of guava size by primary school pupils in Bungoma County. Small fruit <4cm; medium fruit 5-7cm and big fruit >8 cm

Guava taste

Mean hedonic rating for guava taste types is shown in Table 6. The taste preferences are presented in Table 7. The pupils rating of sweet type guava ranged from like to like very much (Table 7). The most liked guava taste type was sweet type (liked by 88.3 %), followed by salty taste type (liked by 56.9 %) and finally bitter/sour taste type-liked by 30.4 % of the pupils. There was no significant difference (p>0.05) between male and female pupils regarding the preference of the difference guava taste types (Table 8).

Table 6. Mean hedonic rating of taste of guava by pupils in Bungoma County

Guava taste type	**Mean hedonic rating for guava taste types**		
	Bungoma North (N=102)	Tongaren (N=95)	Overall sample (N=197)
Sweet type	4.75±0.06	4.11±0.16	4.44±0.09
Salty type	3.43±0.14	2.81±0.15	3.14±0.10
Bitter or sour type	2.99±0.16	1.95±0.15	2.29±0.12

Values are mean ± SE   A 5-point hedonic rating scale (5=Like very much, 1=Dislike very much)

Table 7. Preferences for the various tastes of guava by pupils in Bungoma County

Guava taste type	**Sub-county**	**Guava taste preference (%)**					
		Like very much *(score 5)*	Like *(score 4)*	Neutral *(score 3)*	Dislike *(score 2)*	Dislike very much *(1)*	Total
Sweet type	Bungoma North	82.4	13.7	2	1	1	100
	Tongaren	66.3	13.7	2.1	0	17.9	100
	Overall	74.6	13.7	2	0.5	9.1	100
Salty type	Bungoma North	25.5	44.1	6.9	13.9	8.8	100
	Tongaren	22.1	21.1	2.1	35.8	18.9	100
	Overall	23.9	33	4.6	24.5	13.7	100
Bitter / sour type	Bungoma North	27.5	15.7	14.9	10.9	30.9	
	Tongaren	14.7	2.1	9.5	10.5	62.1	100
	Overall	21.3	9.1	12.2	10.7	45.7	100

A 5-point hedonic rating scale (5=like very much, 1=dislike very much)

Sweet tasting guava fruit

Overall, majority of the pupils 74.6 % liked very much the sweet taste type of guavas, 2.0 % were indifferent in terms of preference of the sweet type of guava and 9.6 % disliked the sweet type of guava (Table 7).

Salty tasting guava fruit

Salty taste type guava was liked by 56.9 % of the pupils, and 4.6 % were indifferent in terms of preference of the salty type guava; 38.2 % disliked the salty taste type guava (Table 7).

Bitter or Sour tasting guava fruit

30.4 % of the pupils liked the bitter/sour taste, 12.2 % were indifferent and 56.4 % disliked it.

Comparison of sensory analysis data between males and female respondents

To enrich the study gender comparisons were conducted to determine its contribution to preferences on guava consumption amongst pupils in primary schools in two sub-counties of Bungoma County.

Table 8. Comparison of sensory analysis data between male and female pupils

Categorical variables	Category	Males (n=102) %	Females (n=95) %	*p*-value	χ^2-value
Do you like eating guava	Yes	99	99	0.983	0.000
Guava shape and skin colour:	Very round fruit orange skin	15	18.6	0.504	0.447
	Oval fruit & dark yellow skin	60	49.5	2.198	0.138
	Round/oblong & dark green skin	59	62.9	0.312	0.576
	Oval fruit nipple & dark yellow skin	14	10.3	0.627	0.428
	Round fruit yellow green skin	74	75.3	0.041	0.839
	Round fruit pale yellow skin	37	39.2	0.099	0.753
	Round fruit orange/green skin	8	6.2	0.246	0.620
	Round fruit orange green skin	13	6.2	2.624	0.105
Guava flesh colour:	White	22	33.0	2.989	0.084
	Cream	15	5.2	5.232	0.022
	Pale pink	41	34	1.023	0.312
	Light pink	19	7.2	5.968	0.015
	Pink	57	57.7	0.011	0.917
	Dark pink	72	85.6	5.403	0.020
	Orange pink	17	13.4	0.494	0.482
	Rosy pink	16	2.1	11.522	0.001
Preferred guava size:	Big fruit	47	28.9	6.868	0.009
	Medium fruit	61	75.3	4.601	0.032
	Small fruit	4	4.1	0.002	0.965
Preferred form of guava consumption:	Whole fruit yellow skin, pink flesh	73	66.0	1.146	0.284
	Rind of pink flesh guava fruit	16	13.4	0.265	0.607
	Only seed of pink flesh fruit	22	17.5	0.621	0.431
	Whole fruit green skin,white flesh	46	62.9	5.658	0.017
	Rind of white flesh guava fruit	5	8.2	0.842	0.359
	Only seed of white flesh guava	13	9.3	0.687	0.407
Preferred guava taste	Sweet tasting fruit			7.544	0.110
	Salty tasting fruit			2.525	0.640
	Bitter/ sour tasting fruit			7.865	0.164

n=number of respondents SE=Standard error of the mean; Small fruit <4cm; medium fruit 5-7cm and big fruit >8 cm

Discussion

Despite rich agrobiodiversity in Western Kenya, the level of malnutrition among children is quite high (Ndungu *et al.,* 2013). High incidences of malnutrition and health related ailments are occasioned by low utilization of local foods and fruits. Guava is among the popular underutilized fruits in Kenya (Maundo *et al.,* 1999, Anastacia *et al.,* 2010, Njogu *et al.,* 2015). The wide geographical distribution of this neglected and underutilized species, coupled with high rates of malnutrition that make Western Kenya the ideal location to study the role and potential of local underutilized fruits and farming systems to contribute to good nutrition (Termote *et al.*, 2014, Njogu *et al.*, 2015) as well as to study the preferences of pupils in primary schools as opportunities to enhance utilization of this crop. In this study 77 % of the respondents had at least 1-5 trees on their farm or home. This data supports Njogu *et al.* (2015) findings that one of the frequently mentioned fruit species in Western Kenya was guava (62 %). From these results, it is important to ensure that we explore and produce the preferred guava types that local food systems offer in a cost effective and sustainable manner. Moreover, the results indicate that ripe guava fruits are available half the year from March to August. The guava season is longer in Western Kenya than in Eastern Kenya where the fruit is only available for four months (March to June) according to Kehlenbeck *et al.* (2015).

A 'wholesome diet' approach that goes beyond single food-single nutrient solutions will be necessary to address the triple burden of malnutrition (undernutrition, micronutrient deficiencies as well as over-nutrition) simultaneously. Effective food-based dietary strategies are one of the most sustainable nutritional interventions, as long as nutritionally adequate diets based on local foods can be successfully identified and promoted (Ferguson *et al.*, 2004). The case for guava in this study whereby most (99 %) of the pupils like consuming guava can be used as an opportunity to diversify fruit choices in Western Kenya. Guava consumption preferences vary whereby most primary school pupils preferred to eat the whole fruit but some ate only the rind or seed. Although most respondents preferred fruit with yellow skin and pink flesh, there were significant differences in gender when it came to colour of flesh i.e. dark pink (0.020), rosy pink (0.001), light pink (0.015) and cream (0.022). The respondents generally preferred round bright yellow fruit which is the completely ripe fruit. When it came to taste, most pupils (74.6 %) preferred sweet tasting guava, followed by the salty type (56.9 %) and the bitter/sour (30.4 %) type.

Studies have shown that dietary diversity is associated with improved nutrition (Ruel *et al.*, 2004). Kenya is among the regions endowed with a rich biodiversity of indigenous neglected and underutilized fruit species (Ndungu *et al.*, 2013, Njogu, *et al.*, 2015; Nyamongo *et al.*, 2015). Many cultivated and wild species and varieties have potential to contribute to diets and nutrition in Kenya (Kehlenbeck *et al.*, 2015). Unfortunately, with increasing globalization and social change processes, traditional knowledge on local agrobiodiversity is rapidly declining (Sogbohossou *et al.*, 2015). Diets as well as farms have become less diverse as ecosystems are destroyed to promote monoculture of cereal or industrial crops. Underutilized fruit species have adapted to local environmental conditions and as part of the locally available agricultural biodiversity, thus building system resilience and supporting household subsistence. Results from this study contribute towards supporting the increased cultivation of guava in farming systems of Western Kenya. This paper contributes towards developing tools and approaches to document traditional knowledge/use and monitor preference for cultivated and underutilized fruits. This work is part of a study on assessing dietary patterns and nutritional gaps for different age groups and gender. The results presented in this paper will contribute to developing guidelines for community action research to improve dietary patterns and nutrition including community-based nutritional educational interventions.

Climate change is expected to pose a serious threat to food security of resource-poor farmers in Western Kenya. Crop production rates are estimated to drop a further 8 % (IPCC, 2014) to 15 % in areas in which farmers are already struggling to feed their families throughout the year (Mubiru and Kristjanson, 2012, Kehlenbeck *et al.*, 2015). Climate change and the associated alterations in weather patterns, rainfall distribution and the occurrence of floods and drought are affecting communities in their ability to maintain and use their genetic resources (Nyamongo *et al.*, 2015). Farmers traditionally rely on a wide portfolio of crops and crop varieties for their diets, for sustenance and income generation which they grow on their farms or collect in the wild. Farmers also maintain crop genetic diversity to be able to cope with fluctuating soil and environmental conditions (Nyamongo *et al.*, 2015) and because of this often grow more varieties of the same crop. The respondents in this study were able to identify all the diverse types of guava presented to them in the questionnaire. Monoculture practices of agriculture and the associated loss of biodiversity have decreased the resilience of agricultural systems. Facilitating access to a wider range of agricultural biodiversity will give communities enriched nutritious food options.

Conclusion

This study demonstrates that preference for guava changes between gender and are based on availability of type. The results indicate that the portion of fruit consumed must be considered when undertaking nutritional studies of guava where some ate the whole fruit, others ate only the seed or only the rind. In Western Kenya, fruit with green skin was preferred indicating that children in this region tend to eat guava fruit before they fully ripen and achieve the yellow colour.

People have long adapted their food systems to changing circumstances and experiences, incorporating new foods and practices and dropping others along the way. However, these complex and diverse food systems are endangered today, dependent as they are on threatened traditions and biologically diverse environments. This could be due to the recent increase in human population and associated industrial agriculture, unsustainable resource extraction confounded by loss of traditional resource management practices, erratic weather, occasional conflicts and potential effects of complex development activities.

Developing, testing and applying the tools and approaches described above in different primary schools provided the necessary scientific evidence to scale guavas that are sweet, have pink or white flesh based on preferences by communities in Western Kenya. It showed that nutritional value data for guava should be fractioned to whole fruit, rind and seed parts instead of the whole fruit only approach.

The key challenge is to link, in a scientifically-sound way, sets of information on the detailed taste and morphological data of guava types, with the students' preferences. This information could be of great interest to breeders, who could better target their efforts to meet farmers' needs. This is particularly true where varieties are developed for different agro-ecologies. A decentralized, participatory and diversity-based approach will be of greater benefit for rural communities. This step allows us to identify crop varieties that better match farmers' needs and expectations and to link them with agro-morphological data measured by scientists. Linking these sets of information will contribute to further narrowing down the number of varieties for breeding to bridge performance and preference of varieties in the broadest possible geographic areas. Creating variety selection systems for the different underutilized fruits is therefore a crucial step for the sustainability of the system.

Acknowledgements
The authors of this appreciate the teachers and students of Maresi FYM (Friends Yearly Meeting) Mission, Matisi PAG (Pentecostal Assembly of God), Kananachi FYM, Chuma PAG, Matisi PAG, and Mitua FYM located in Bungoma County, Kenya. They also thank farmers (Tete Farm) who allow their farms to serve as conservation sites for local biodiversity.

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Defects in Plantation Soft Wood in Kenya: Causes, Extend and Distribution

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Abstract

Kenya forest sector has significant economic, environmental, social and cultural values. Estimates indicate that the sector contributes approximately 3.6 % of Kenya's gross domestic product (GDP). Currently, the forest industry is vibrant, undergoing a number of remarkable positive changes after a long period of harvesting ban. However, the industry is considerably challenged by the quality of the available round wood, which is the primary raw material. This paper reports on the magnitude of defects found in *Cupressus lusitanica* and commonly used. The study analysed data collected from all regions where defects were identified. Results indicated that defect in sawn timber was common in all plantation areas in the country, ranging between 23 and 37 %. On the average, over 91 % of all the defects observed were due to a combination of heart rot and *oemida gahani*, a common pest in Cypress wood. Peculiar cases (0.4 %) involving termite attack on standing *Curessus lusitanica* trees was observed in western region. The magnitude of the defects significantly differed among different regions. Much of the damage was associated with small mammals (Monkeys) particularly in Mau and central Kenya regions, while in Mt. Kenya and Aberdare regions, defects are is highly associated with large mammals including buffaloes and Elephants. The age of the trees had a significant influence on the magnitude of defects even within the same region. The study recommends that there is need to develop strategies to reduce the primary causes of defects and increase the quality of raw materials available for the wood industry. Although efforts have been put through installation of electric fence keeping out elephants from plantation forests in Mt. Kenya and Aberdare, monkeys still pose a major challenge. Further, there is need to improve silvicultural treatment and harvest trees at optimum rotation age to avoid extended damage of the wood in case there is initial attack causing any of the defects. The study further recommends diversification of species and introduction of Bamboo as an industrial material particularly in high altitude areas.

Key words: soft wood, defects in timber, wood industry, heart rot

Introduction

Timber processing, especially from plantation forests plays a major role in Kenya's development (Republic of Kenya, 2016). Sawmilling provide employment directly and indirectly to many people in forested rural areas (KFS, 2014; Muthike, 2016). During the 1999-2011 ban that locked out the wood industries from state forests, wood supply to wood industries was t reduced and most of the timber industries, particularly those in the Small and

Medium Enterprise (SME) category closed down. This adversely affected socio-economic development with reduced employment opportunities especially in areas where the local economies depended on the industry (Muthike *et al*., 2010).

The period of the ban posed more than a decade of minimal management inputs into forest plantations and low harvesting. This resulted in poor stocking levels of forest stands and low quality wood for the industry (Muthike and Githiomi, 2017). Currently, plantation forests are not optimally distributed due to a large gap between over mature and very young plantations. In addition, there had been inadequate silvicultural operations leading to poorly formed mature stems and prevalence of pests, diseases and game damage, which caused heart rot in wood. With the steady increase in demand for round wood from the expanding industry, there is already a general decline in supply of mature round wood for specialised uses like plywood and sawn timber for structural use. This shortage is likely to increase and affect many other uses due to the skewed tree population distribution (IUCN, 2001). To date, the inventoried plantation forest land base covers 134,861 ha, of which 95,027 ha is stocked (MEWNR, 2013).

Additionally, there has been numerous complaints of defective logs at varying magnitudes in some plantations, further reducing the available quality round wood. The main defects reported include presence of *Oemida gahani* (Dist) attacks and by extension heart rot. These are highly associated with mechanical damage on the trees particularly during early stages of growth. Mechanical damage of trees involves bruising or stripping of the stem bark or break tree tops and branches. This exposes the wood material, allowing rain water and microorganisms to penetrate into the wood cells. Most of the mechanical damage of trees is associated with wild animals and particularly elephants and buffaloes. Smaller mammals including sky monkeys break tops and branches of young trees in search for food. Domestic animals mainly cattle and goats cause damage to young trees where grazing is allowed in plantations.

Oemida gahani (Dist) has been documented as an important pest in East Africa (Webster and Osmaston, 2003; Curry, 1965). This is a beetle which inhabits dead wood of mainly *Cupressus* and *Juniperus* species. The beetle lays its eggs on any opening of living trees with large pruning scars, stripped bark or broken tops and branches. The eggs hutch into larvae, which burrow into the wood and restrict themselves in the inner dead part of the stem called the heartwood.. As the tree continues to grow, although the entry wound may close up (if it was small), the larvae continue to develop and slowly begin to destroy the wood cells, compromising the structural integrity of the wood material and progressively develop into wood rot.

Apart from the two species mentioned above, several other indigenous and exotic species have been known to play host to *O. gahani* (Curry, 1965). Some of the known methods used to control the spread of this pest include burning debris of host species in an area before planting, replacing host tree species with non-host ones and controlling animals from particularly young plantations. Timely pruning before the branches mature and treatment of large pruning scars also help to minimize possibilities of entry of the pest (Terry and Curry, 1964).

In addition to *O. gahani* attack and heart rots, spiral grains and reaction wood have been reported particularly in areas with strong winds and steep terrains. Peculiar cases of termite infestations on standing *Cupressus lusitanica* trees has also been reported in some drier parts of Western and Lake Victoria as well as Eastern regions. It is probable that the termites find easy entry into the wood of living trees through already destroyed heart wood particularly if that destruction goes down to the base of the tree. This study investigated the extend of these defects, distribution among the main softwood regions and their effect on merchantable wood of the common soft wood timber species.

Study Methods

The study involved assessment of plantations in different regions in the country where complaints of defects in logs had been registered. The plantation registers were examined in each case to provide information on the history of plantation in terms of silvicultural treatment and any observations made on the onset and cause of damages to the trees. The assessed plantations were classified according to their age, size and region in which they were grown.

Assessment of the defects in wood was done using standard sawmill test procedures and was carried out between the years 2014 and 2017.This period was chosen because it coincided with active operations in the state plantations after the logging ban. The period registered many complaints of defective wood and requests from the wood industry. In each of the identified plantation, trees were randomly sampled, marked, felled and cross cut into commercial log lengths using chain saws. Log diameters were measured to the nearest centimetre at the butt, top and at every 0.5 m intervals along the length using diameter tapes (ISO, 1983). Log lengths were measured to the nearest 0.1 m using a linear tape. The total volume of all the logs in each case was computed using Smalian formula; Equation (1) (ISO, 1983), where V_l is the total merchantable log volume, L is the merchantable log length, D is the log mean diameter and π is a constant with a value 3.142.

$$V_l = \sum \left(\frac{\pi D^2}{4} L \right) \quad (1)$$

Logs were converted into sawn timber using the most commonly used sawing systems in Kenya; circular, broad band or narrow band saws. The total volume of the resultant sawn timber (V_t) was computed as shown in Equation (2) (ISO, 1974), where b is timber breadth, d is timber depth, l is timber length. Timber recovery rate (R %) was computed as a relationship between total log volume (V_l) and total volume of the resultant sawn timber (V_t) as shown in Equations (3) (ISO, 1974).

$$V_t = \sum (bdl) \quad (2)$$

$$R\% = \left({}^{V_t}/_{V_l} \right) 100 \quad (3)$$

The sawn timber was subjected to scrutiny to identify the pieces that are affected by *O. gahani* and/or heart rot and any other pest related defects. Any piece found affected to more than two thirds of its length was rejected, otherwise the defective part cut off and the piece re-assessed again based on the Kenyan grading standards for soft woods (KSO2-711). The total volume of the rejected timber was computed again using formula 2 above and expressed as a percentage of the total sawn timber volume.

Results and Discussion

Regional distribution of defects in softwood plantations

Table 1 shows the distribution of defects in softwood and their primary causes within various regions as assessed between 2014 and 2017.

Table 1. Regional distribution of defects in forest plantation softwood

Region	**Number of Plantations**	**Area (Ha)**	**Proportion (%)**	**Mean Defect (%)**	**Primary Cause**
Central Kenya	3	54	8.4	22.3	Monkeys
Aberdare	12	182	28.3	34.6	Elephants
Mt. Kenya	5	137.6	21.4	31	Elephants
Mau	8	171.4	26.6	28.6	Monkeys
North Rift	2	36.5	5.7	32.5	Monkeys
Eastern	1	10.3	1.6	37	Monkeys & Termites
Lake/western	3	52	8	33	Monkeys % Termites
	Σ=34	**Σ=643.8**	**Σ=100**	**μ=31**	

A total of 622 ha. of *C. lusitanica* plantations were reported to contain wood with defects in the main softwood plantation regions in the country. Visual observation of the plantations under study showed very few signs of damaged stems except for some cases of broken tops and in some cases a few trees with signs of early injuries but recovery of the bark. Majority of the plantations assessed were observed to have characteristically high stocking density and branchy trees of small diameter and poor quality stems. This was an indication that they must have had little or no silvicultural treatment at all.

Of the plantations studied, the largest proportion was assessed in Aberdare, Mau and Mt. Kenya regions with 28.3 %, 26.6 % and 21.4 %; respectively. Relatively smaller areas were found in the other regions, the smallest being in Eastern region, where only one plantation was reported and assessed as defective. This plantation had the highest percentage defect in wood (37 %) followed by Aberdare and North Rift (35 % and 33 %), respectively. The lowest mean defect (22 %) was in Central Kenya region.

The main initial cause of defects is injury to the trees particularly at the young age. The injuries were mainly attributed to large mammals in Mt. Kenya region. In Aberdare region, a combination of large and smaller mammals is highly associated with damages to trees especially in Nyandarua.. In Central, Mau and North rift regions, injury to trees was mainly as a result of the smaller mammals.

Poor silvicultural treatment or no treatment could have contributed to the damage of the trees. During the time of the logging ban, very little activities took place within the plantation areas. There was neither forest farming nor silvicultural practices. This scenario could have promoted the presence of smaller mammals within the plantations and damage to young trees in search for food. In areas with larger mammals, the trees had visible damages. The damage reduced after the installation of electric fences.

Some cases of damage were attributed to domestic animals (cattle and goats) especially in areas where human populations around the forests was large, leaving little land for animal grazing on private farms. The areas included Koibatek in Mau Region, Lari forest in Aberdare region and Kakamega forest in Western, where animal grazing in the forest has been historically a dominant practice.

Injury to trees opens the bark which is technically the protective covering of the tree. Microorganisms gain entry into the wood and become agents of wood cell destruction, targeting the Cellulose fibres and tracheids which are the structural elements of the wood material. At early stages of attack, it is easy to observe cases of *Oemida* attack characteristics. This leads to rotting of the wood elements and hollow parts develop particularly along the stem pith. Stem rot develops either from the bottom upwards or from the top downwards depending on the part of the tree that was initially injured. In some cases, butt logs were found to be more damaged than the middle and top logs. In stems where damage was more pronounced from the bottom, termite infestations were also observed, burrowing the centre of the stem upwards and filling the gap with soil. In drier and hot climates like in the case of Eastern and Lake Victoria/Western regions, the tree begins to be destroyed around the butt at early age. This could be reason why the rate of defects in such wood was quite high (37 and 33 %) in Eastern and Western/Lake regions, respectively.

Effect of tree age on level of defects in the wood

Table 2. Effect of age on defects in softwood forest plantations

Plantation Age (Yrs)	Number of Plantations	Area (Ha)	Proportion of Area (%)	Mean Defect (%)
< 30	8	104.1	27.5	23
30 - 40	18	323	50.2	31.1
> 40	9	216.7	22.3	35.3
Total	**34**	**643.8**	**100**	**29.8**

Tree age seemed to positively influence defects in the wood. Out of a total of 34 plantations assessed during this study, 27 were above 30 years at the time of assessment, which constituted 79.4 % of plantations with defective wood and constituting equivalent of 539.7 ha (72.5 %) of the plantation area assessed. Table 2 shows the effect of tree age on defects in forest plantation softwood. Those aged below 30 years were fewer (27.5 % of the plantation area assessed). Similarly, the level of defect increased with tree age, being significantly higher in plantations above 30 years than in those below. There was a clear trend of increasing level of defect with increasing tree age. Exceptional cases were observed in Kakamega and Vihiga in Western region where 17-year-old plantations had the highest levels of defects (36 % and 30 %, respectively) observed in this study. This was however highly attributed to a combination of rot and termite attack on the trees. Most of the other plantations below 30 years of age had lower defect percentages than older ones.

As discussed above, when the trees have had bruised bark or broken tops at early age, microorganisms attack progressively causing damage to the tree structural elements as the organisms feed on the cellulose material in the wood. Over time, further damage is realised upwards or downwards along the stem. If the trees are harvested at earlier age, the level of damage is lower than when the affected trees are left unharvested for a longer period. Trees continued to grow through the years with neither thinning nor clear fell harvesting. Those plantations that had been damaged and subsequently developed microorganism attack then progressively developed rots, which continued over the years.

The Financial Implications of the Defects in Wood

The results of this study showed 30 % of the 643.8 hectares of *C. lusitanica* plantations studied were defective and cannot be economically utilized. This translates to 193 hectares and assuming a normal mean stocking of 266 stems per hectare, a mean merchantable log volume of 1.3 m^3 for a mature *C. lustanica* tree and a total of 66,739 m^3 of round wood is defective. This further translates to a loss of Kenya Shillings 266,957,600 (US$ 2,669,576) at the rate of KES 4,000 per cubic meter of *C. lusinatica* round wood. More pronounced is the loss the industry suffers when this wood is extracted and sawn because the product is rejected after incurring the logging and processing costs.

Conclusions

- The presence of wild and domestic animals is a catalyst to tree damage, which eventually become the beginning of defects in the wood.
- Mainly *C. lusitanica* plantations were affected by the defects observed.
- Results and observations linked lack of/or delayed silvicultural treatment to development of defects in *Cupressus lusitanica* wood.
- Delayed harvesting of trees beyond the rotation age promotes progression of defects in soft wood.

Recommendations

- As installation of electric fencing continues to keep off large mammals out of forest plantations.
- There is need to develop strategies to deal with smaller mammals especially monkeys in forest plantations areas
- Plantations should be well monitored for any signs of attack, especially when they are known to have suffered some damage. Early assessment for defective wood would help identify plantations that may not need to be left until they reach rotation age. In cases where a plantation is observed to have defects at the commercial thinning stage, it would be prudent to clear fell the plantation at that stage to save the wood from further damage as the plantation waits clear felling at rotation age.
- The study strongly recommends replacement of *C. lusitanica* with Pinus species whose quality and strength properties are similar.

Acknowledgements

The authors acknowledge the facilitation received from both Kenya Forestry Research Institute (KEFRI) and Kenya Forest Service (KFS) during data collection and analysis. We also are thankful to the various sawmill owners who facilitated logging and timber processing exercises.

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Piloting Biomass Energy Audit for Energy Conservation in Homa-Bay County, Kenya

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Abstract
Biomass energy is a source of energy for over 70 % of Kenyans and 90 % of rural population are depended on it. However, the traditional ways of producing and utilizing the biomass energy is inefficient and therefore unsustainable. It is therefore necessary to undertake energy audits to determine areas of wastage and identify potential strategies for biomass energy conservation at house and institutional level. Piloting biomass energy audit was undertaken in Homa-Bay County. The study aimed at identifying types of cooking devices and amount of biomass energy used at household/institution levels and its contribution to monthly bills and outline potential strategies to reduce energy consumption. A semi structured questionnaire and an energy audit tool were used to collect information from the respondents. Results of the study showed that biomass energy is the main energy source for majority of the respondents for cooking and heating. The inefficient traditional three stone and the metal cook stoves are the most preferred types of stoves. Firewood at household level is sourced from own farms and neighbouring forests while firewood and charcoal used in institutions and charcoal for domestic use is bought from local markets. On average 30 % cost of biomass energy, this has contributed significantly towards higher energy bills, in institutions and as well as at household's levels. The study concludes that energy efficiency audit is critical for consumers to identify areas of energy wastage. The study recommends energy audit as well as use of energy saving technologies as tools for energy conservation for reduced energy bills.

Key words: Biomass energy, conservation, audit, Homa-Bay

Introduction
Globally, biomass provides 10 per cent of primary energy. It is a source of energy for over 2 billion people who rely on traditional biomass energy in form of wood fuel, agricultural residues and animal wastes for their basic energy including, cooking, heating and lighting. In recent years, biomass energy has also become a source of fossil-fuel free electricity especially in developed world (WB2011). Fuel wood and charcoal production contributes 68 % and 10 % respectively to renewable energy sector globally and has major effects on forestry as most of these products come from forested and woodland areas especially in Africa and Asia countries (FAO 2014, WBA, 2016). While in other developing countries the demand for biomass energy has peaked in Africa, especially in Sub-Saharan Africa (SSA), the demand for biomass energy will continue to grow to near future and the number of consumers is projected

to reach almost one billion by 2030 according to world energy outlook. This is due to high population growth rates, rapid urbanization and high prices of alternative energy sources such as gas or electricity. (UNDP/ WHO, 2009, WB, 2011). This is despite its negative environmental and health impacts related to its production and use with over 4 million deaths related to use of solid fuels reported in 2012 (WHO,2014).. This demonstrates the critical importance of biomass energy in meeting the primary energy needs of the people in the lowest economic ladders of those countries depended on it (Githiomi *et al,* 2015). With increased awareness on issues contributing to climate change and energy insecurity, biomass energy has become far more important and visible as a global issue and has the potential to contribute to energy security, climate mitigation and sustainable rural development among others if sustainably managed.

In Kenya, there are three main sources of energy. These are wood fuel, petroleum, electricity and others accounting for 70 %, 21 %, 9 % and 1 % respectively (UNEP/MoE, UNDP, 2007) With limited access to modern clean fuels and increased levels of poverty, there is increasing demand for biomass energy on the lower and middle levels of the traditional energy ladder such as fuel wood and charcoal. It is estimated that the national demand of charcoal is over 16 million m^3 while supply is estimated at about 13.5 million m^3. The current deficit is estimated to be over 60 % (MEWNR, 2013, GOK 2014.). Wood fuel is the main source of basic energy for majority of Kenyan households for cooking and heating. It's also an important source of energy for small and medium enterprises (SMEs) such as agro-processing industries such as tea and tobacco drying, fish processing, the textile dying industry, metal processing industries like blacksmiths and mineral-based industries such as brick making and ceramics/ pottery which uses fuel wood and other biomass in kilns (Githiomi *at el.,* 2010 Githiomi, *et al.*, 2012, FAO, 2006). Biomass energy is also increasingly being used in institutions such as schools, hospitals, prisons and restaurants which require large amounts of fuel due to the large amount and variety of meals prepared. The demand for biomass energy both in the domestic, institutional and commercial sectors has been on the rise due to a number of factors including increasing population, rapid urbanization and high cost of alternative fuels such electricity and liquefied petroleum gas (LPG)**.** Biomass fuel is largely used in rural areas, where it is regarded as a cheap source of energy and thus there is need to look for strategies to save the resource. Use of biomass energy conservation technologies with improved efficiency levels, widely being promoted in Kenya can greatly reduce consumption levels and deforestation for wood fuel production. It is also important to undertake energy audits which will help consumers identify areas of wastage, available energy conservation technologies and alternative fuels such as briquettes from agricultural and forest wastes for reduced exploitation of tree/ forest resources.

Energy audit is assessment of how energy is being consumed within the household, institution or enterprise for purpose of reducing energy consumption thus energy conservation. Conducting energy audit helps identify energy waste and opportunities for energy conservation or improving energy use practices. Apart from identifying and reducing the percentage of energy expense on the overall household or institutional budget, energy audits helps the consumer to know the amount of wood fuel energy being consumed within an institution or household, cuts on time and costs of obtaining the fuel and as a result as well as reducing carbon emission and increased deforestation thus contributing to climate mitigation.

Problem statement and justification

Biomass energy is the main source of energy for over 95 % of the habitants of Ndhiwa Sub-County, (GEP, 2015). However, production and utilization is unsustainable as the technologies used are inefficient and has significantly contributed to increased overexploitation of tree resources, environmental degradation and high energy bills at institutional and household level. Unsustainable harvesting of tree/forest resources and continued use of inefficient technologies has also led to increased emission of greenhouse gases, a major factor to climate change. Adoption and use of alternative clean fuels such as briquettes is still low despite the availability of adequate sugarcane bagasse as potential feedstock for production. From Green Economy Project baseline studies, there is low adoption of efficient biomass energy conservation technologies such as efficient charcoal conversion kilns, domestic and institutional energy saving stoves as well as low establishment of wood fuel plantations for wood fuel production as most of the available land is being cleared for expansion of sugarcane plantations and nonexistence of energy audits at domestic and institutional level. Biomass energy audit was piloted in the study area to document biomass energy technologies being used in the community, determine areas of biomass energy wastage and identify potential remedial measures. This paper outlines the process and outcomes of the study.

Objectives of the study

1. To identify types of cooking devices used in the community (domestic and institutional) in Homa Bay county, Kenya;

2. To determine the amount of energy used per household/institution and its contribution to the overall budget bills in Homa Bay county, Kenya

3. To outline potential strategies to improve energy efficiency, reduce energy consumption in household and institutions for energy conservation and improved livelihoods in Homa Bay county, Kenya.

Methods and Materials

The study area

The study was undertaken in Ndhiwa sub-county, (GEP project area), one of the eight Sub-Counties of Homa Bay County. It is located along the south shore of Lake Victoria's Winam Gulf**.** Homa Bay County borders five counties namely; Migori to the South, Kisii and Nyamira to the east, and Kericho and Kisumu to the north east. The county also borders Lake Victoria to the north and west (Figure 1). Generally, the county receives two bimodal rains with the long rains starting from March to June and has 60% reliability. The short rains season starts from August to November. The rains range between 250mm to 1000mm. The Ndhiwa Sub-County has an area of 711.40 Km^2 and a population of 172,212 (GEP 2015, CoGH, 2013).

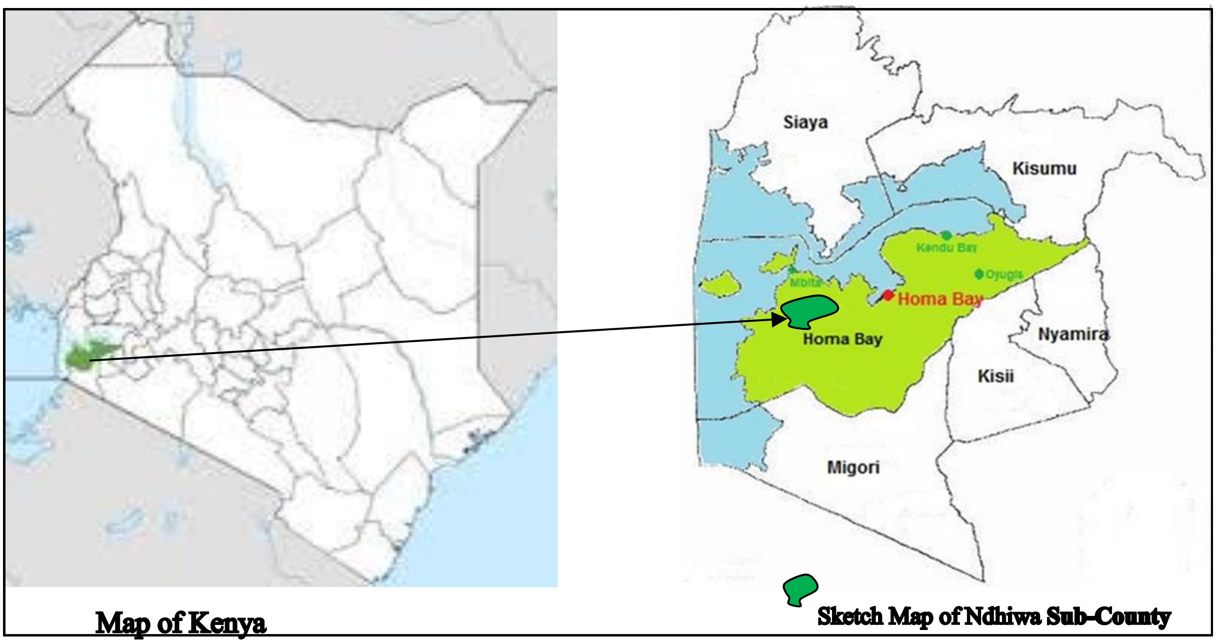

Figure 1. Homa Bay County and the GEP Project area

Sampling and Data collection.

The study area was stratified into 5 strata (wards) and 20 households randomly selected from each stratum. Semi -structured questionnaires were administered to 100 households from the five wards. Institutional questionnaire was also administered to 10 schools and 10 eateries randomly selected. A developed energy audit tool (Appendix 1) was also used for each of the selected households and institutions to collect data on types of stoves used and daily household energy consumption.

Data organization and analysis

Data collected were cleaned, coded and analyzed using Statistical Package for Social Scientists (SPSS) and Microsoft Excel computer packages for descriptive and inferential statistics.

Results and Discussion

Socio-economic and demographic aspects of the respondents

On average, majority of the households interviewed had large families with a mean of six members per household and about 70 % of the respondents indicated that most of the families have at least three meals per day (figure 1), hence the need for adequate fuel to cook the food.

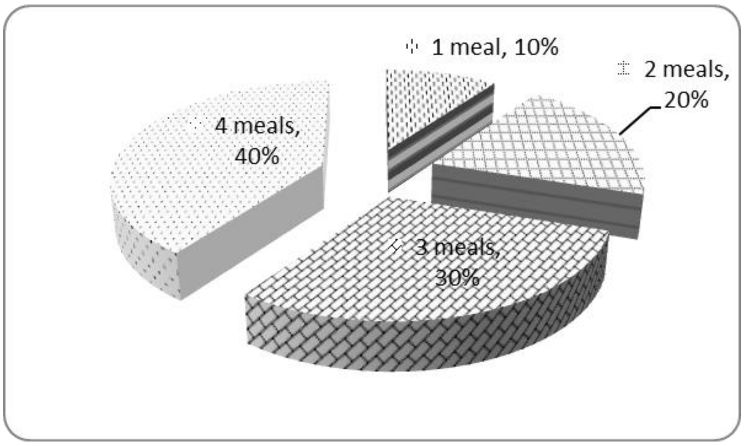

Figure 1. Number of meals per household in the study area.

Sources of income

Subsistence crop farming was indicated by over 50 % of the respondents as the main source of incomes followed by business and formal employment as indicated in (Table 1). Given the high population densities and small land sizes as observed during the baseline survey undertaken in the project area (GEP, 2015), most of the food crops grown are for household consumption and the cash crops grown (sugarcane) is on small scale hence most of the families are financially constraints. Homa Bay County is among counties with high poverty levels at 43.1 % (WB/KNBS 2011).

Table 1. Main source of income

Main source of income	Frequency (n)	% frequency
Crop farming	58	59.8
Business	17	17.5
Formal employment	13	13.4
Casual labour	8	8.2
Livestock farming	1	1.0
Total	**97**	**100.0**

Types of Fuel used in the Community

Biomass energy was the main source of energy for cooking and heating for over 90 % of the respondents. This is as shown in Table 2 with only less than 10 % of the using alternative fuels such as gas and kerosene.

Table 2. Most commonly used energy sources in Homa Bay County Kenya

Energy source	Frequency (n)	% frequency
Firewood	87	50.3
Charcoal	62	35.8
Crop residue	12	6.9
Gas	8	4.6
Kerosene	4	2.3
Total	**173**	**100.0**

Most of the fuel wood and charcoal used was either collected or produced from farms and or purchased from the market as indicated by (70.6 %) and (29.4 %) the respondents, respectively (Table 3). From the baseline survey and observation, most of the forests and the indigenous woodlands have been cleared for agricultural purposes (sugar plantations) hence the few scattered tree on farms are the only source of fuel wood for the community. The households and institutions have to depend on buying wood fuel especially charcoal from the markets. The wood fuel scarcity has also forced the community members to increasingly utilize bagasse from the local jaggeries as source of fuel for cooking as observed during the study. Most of the institutions especially the boarding secondary schools have to order supplies from outside the sub-county as there no adequate tree resources to meet their demands. This scenario provides a potential ready market for charcoal briquettes produced by the community bio-energy centres under the GEP project using agricultural wastes such as bagasse from the sugar mills in the area.

Table 3. Source of biomass fuel in Homa Bay County, Kenya

Source of biomass fuel	Frequency (n)	% frequency
Collect firewood	71	59.7
Purchase charcoal	25	21.0
Produce charcoal	13	10.9
Purchase firewood	10	8.4
Total	**119**	**100.0**

Type of cook stoves used in the community and institutions

The Traditional three stones stoves (64 %) and Kenya Ceramic Jiko (KCJ) (32 %) were indicated by the respondents as the most common types of stoves available in the community as depicted in (figure 2).

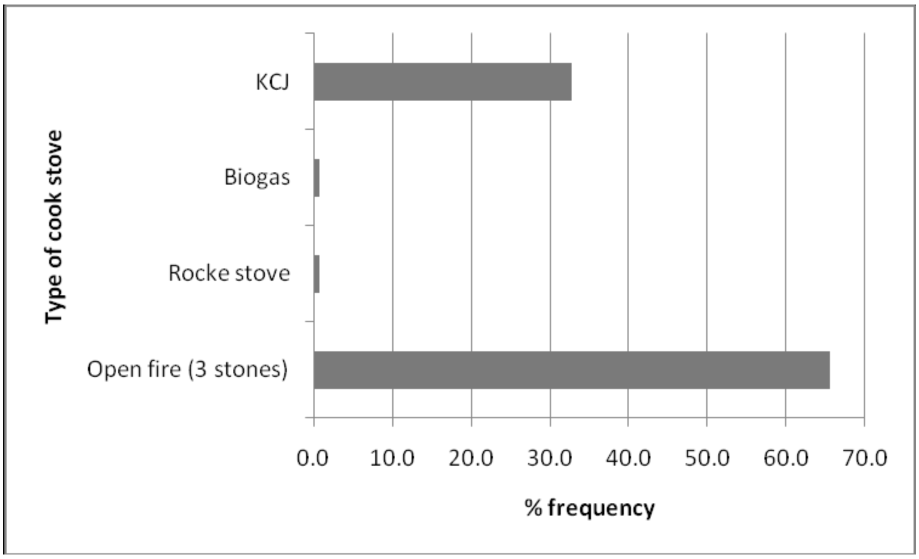

Figure 2. Type of cook stoves used in the household

Though a variety of improved cook stoves are available in the market, the traditional three stone stoves still enjoys preference as it is assembled using local materials (stones) which are readily available. The improved energy saving stoves is available in the shops at a high cost. Their designs, availability and costs were as summarised in table 4. In all institutions surveyed (schools, children home dispensary and the eateries), there was a conspicuous absence of energy saving stoves. Majority of the institutions/eateries were still using the three stone traditional stove and the traditional metal stoves which all consumes lots of fuel wood and charcoal

Though most of the stoves mentioned by the respondents were indicated as available in the local market except the traditional metal stoves, the improved stoves such as Kenya ceramic stove and the modelled clay stoves are expensive, costing between KES 400 to 500 (Table 4). Due to low income levels, these improved stoves are out of reach for most members in the community. The three stone stoves which is freely available enjoy preference by the community since it has been around for generations, uses local materials (stones) which are readily available and can easily be assembled anywhere in the community.

Table 4. Descriptions of the biomass cook stoves available in the community

Description of biomass cook stoves	Type of cook stove	Design and specs	Availability	Price (KES)
Charcoal cooking stoves	Stove	Metal	Scarce	250
	KCJ	Clay lining	Readily available	400
Fuelwood cooking stoves	Modelled Clay Stove	Clay lining	Available	500
	Traditional	3- Stones	Readily available	Free

In a related study undertaken in Peru, Kenya and Nepal on behavioural altitudes and preferences in cooking (Evelyn *et al., 2014*) it was noted that, the traditional cooking stoves were still preferred because the stoves are culturally accepted as they are perceived to yield tasty stable food, are faster in cooking, food more pleasing to the people when associated with traditional stoves, uses locally available materials and apart from cooking, the open fire can be used for other cultural activities. In study by WHO in developing countries on why people use cook stoves, the study found that only a small fractions of the three billion people dependent on solid fuels as source of fuel use improved cook stoves. A large number of the population still use the traditional three stone stoves (WHO/UNDP, 2005) due to a number of factors, chief among them the high cost of improved stoves and high poverty levels among users. This explains why firewood is still the main source of energy for the household even in the study area where over 90 % (Figure 3) of the respondents use the fuel wood as the main source of energy for cooking and heating all year round. Only less than 10 % use it for specific meals in combination with other fuels like liquefied petroleum gas (LPG) or Kerosene indicated by the respondents.

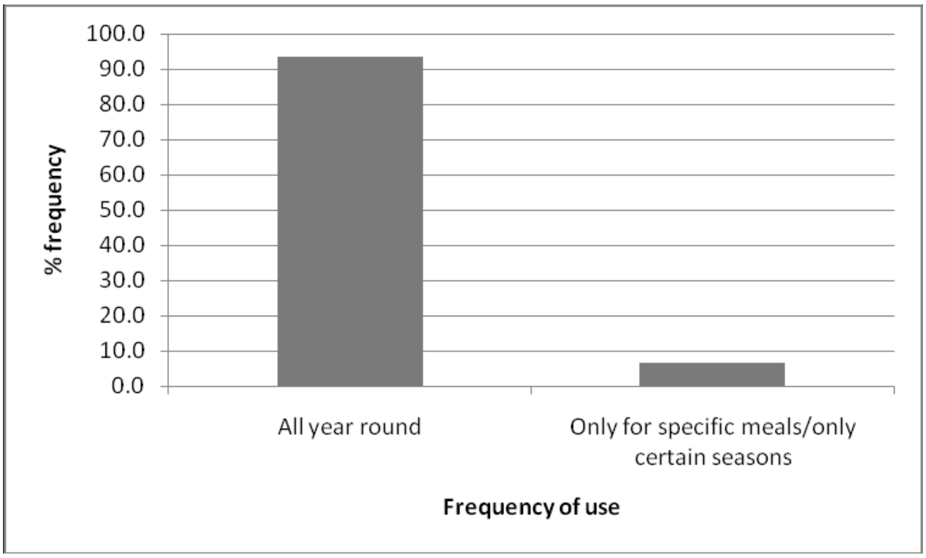

Figure 3. Frequency of use of fire wood

Satisfaction Levels with type of cook stove used

On satisfaction levels with the type of stove used, over 58 % of the respondents were dissatisfied with the type of the stoves they use (Figure 4), which were mainly the traditional three stone and tradition metal stoves. The stoves were indicated as heavy consumers of fuel. The users also have to tend to the fire while cooking as they have to keep on adding fuelwood or charcoal.The stoves are known to be smoky and releases alot of particulate matter (Pollutants) which is a major contributor to increased negative health impacts to the user especially if used in poorly ventilated kitchens or if wet wood is used. Increased use of biomass energy is associated with increased respiratory diseases and the World Health Organization (WHO) estimates that in 2012 over 4 Million people died of diseases related to use of solid fuels in developing countries(WHO/UNDP 2012).

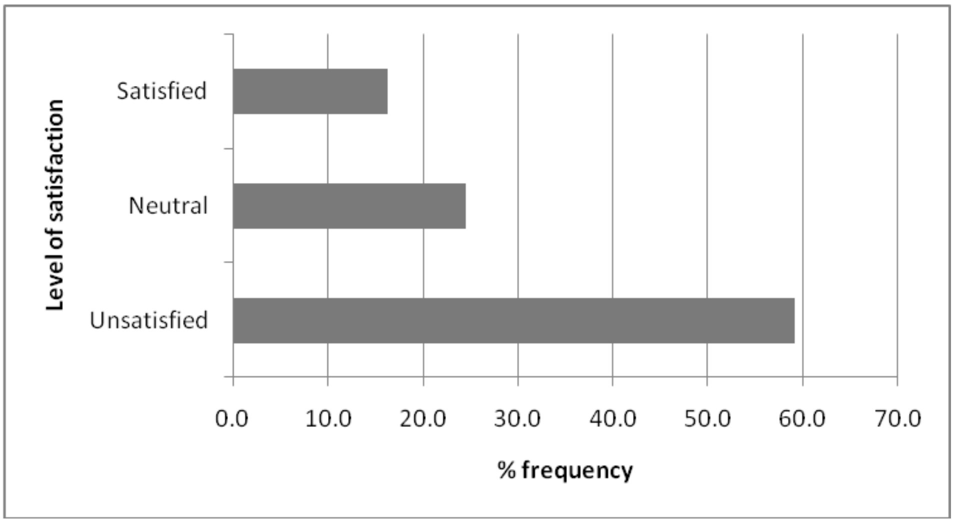

Figure 4. Satisfaction with type of cook stove used

Apart from being smoky, the three stone stoves are known to have ineffficiency levels of 12-15 % (KEFRI 2006). This translates to very high consumption rates of wood fuel and over 70 % of the respondents indicated spending 30 minutes to over two hours (Table 5) collecting firewood twice to four times per week. Use of efficient improved stoves can reduce the amount of wood fuel used thus less time and distance walked in search of the fuel resources.

Table 5. Time spent on firewood collection per trip

Time spent on firewood collection	**Frequency (n)**	**% frequency**
Over 2 hours	14	17.5
Between 1 and 2 hour	26	32.5
Between 30 minutes and 1 hour	19	23.8
Between 10 and 30 minutes s	5	6.3
Less than 10 minutes s	16	20.0
Total	**80**	**100.0**

Distance walked in search of firewood

Apart of the time spent collecting fire wood, the collectors are known to travel long distances in search of fuel resources. Majority of the respondents reported walking between 500 meters and 5 km to collect firewood (Figure 5). This means, respondents have to be away from their farms / families to the neighbourhood in search of fuel wood resources. Promoting establishment of woodlots on farm will reduce the burden women and the girl child who are the majority of the collectors, have to bear every week of travelling long distances and carrying heavy loads which have negative impacts on their health.

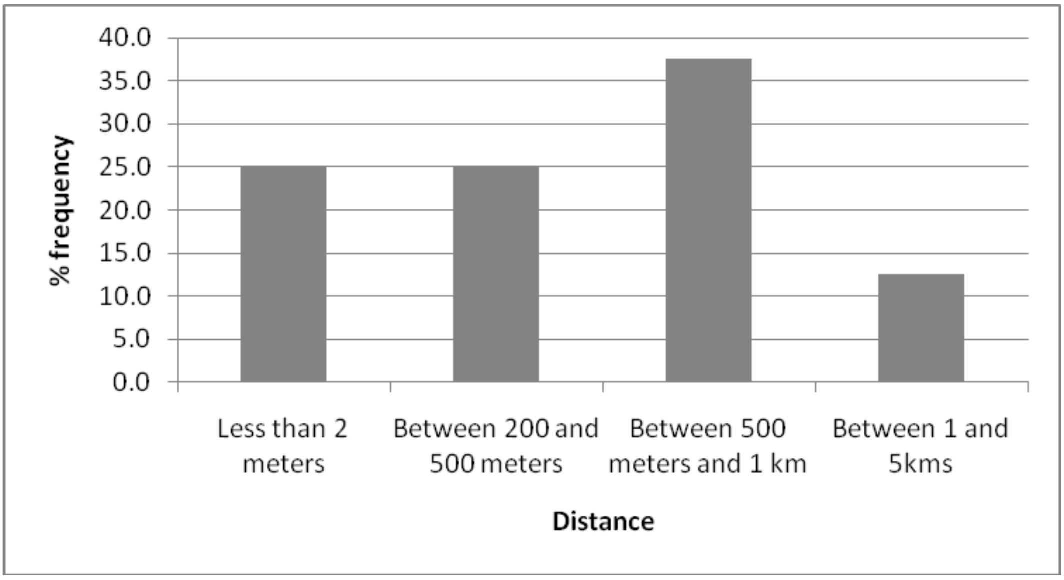

Figure 5. Distance in Kilometres to firewood site

Firewood collectors

In most traditional communities, provision of basic needs like food, water and fuel is the responsibility of women and it was no exception in Ndhiwa community. The results (Figure 6) shows that over 80% of the fuel wood collectors are women (adult female and female child) and that over 50 % of the collectors collected fuel wood twice to four times per week. Given the time taken and number of times per week, means women are spending a lot of their time out there in search of the fuel wood resources. Uses of energy saving stoves with reduced consumption rates will reduce time spend on fuel wood collection for other important socio-economic activities like education for the girls and business opportunities for the women. It will also create more time for the children especially the girl child to participate in other child related activities including playing. The women will have time to engage in business activities for improved livelihood.

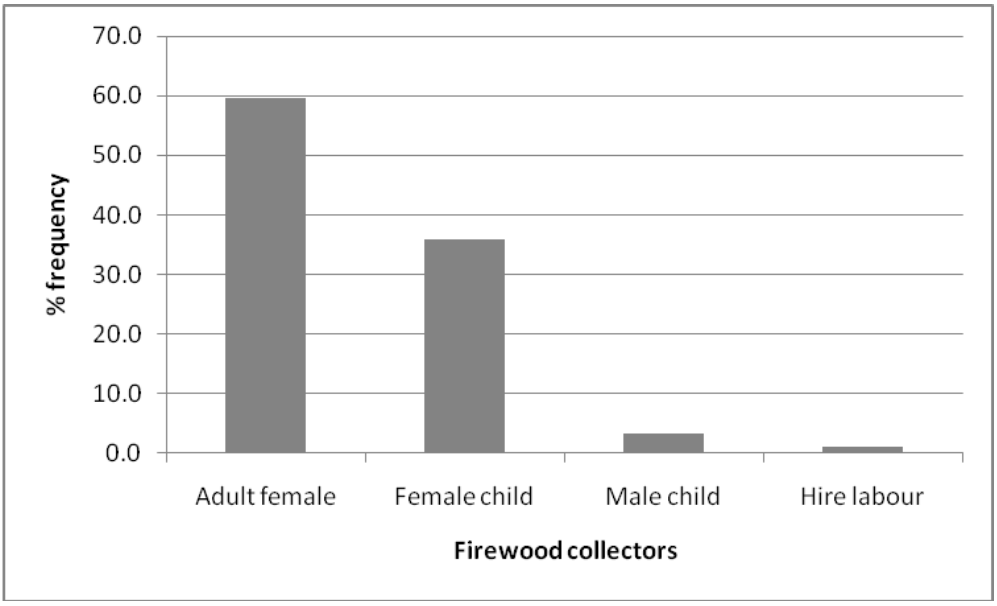

Figure 6. Who collects firewood

Daily household energy consumption (Morning, Lunch and Evening)

On average more food in terms of variety and amount was prepared during morning hours (2.23 kg) than lunch and evening hours (1.18 kg and 1.08 kg, respectively). Traditional three stone stoves which consume more fuel than other types of stoves were used more (67 %) to cook hard foods like dry maize and beans than other types of stoves. Improved stoves using firewood and charcoal were second in choice for cooking (23 %) while Kerosene (7 %) and gas (2 %) were least to use and only for light foods like tea, porridge and rice. Generally, more firewood was utilized by use of traditional stove (4.75 kg) than charcoal.

Comparison between the charcoal stoves shows that, the improved charcoal stove used less charcoal (1.4 kg) to prepare more food than the traditional metal charcoal stove (1.77 kg). Thus in order to save on fuel, money and time spent in search of wood fuel, the community need to adopt biomass energy conservation technologies. From the results, majority of the household (58 %) indicated spending about 3,500 per month on energy alone, which translates to almost a third other monthly expenses.

Daily Energy Consumption by Institution

From the results, all the institutions indicated they use biomass energy in form firewood and charcoal for cooking. Majority of them, (54 %) indicated they mainly use firewood while 46 % indicated they mainly used charcoal (Figure 7) for their cooking and heating.

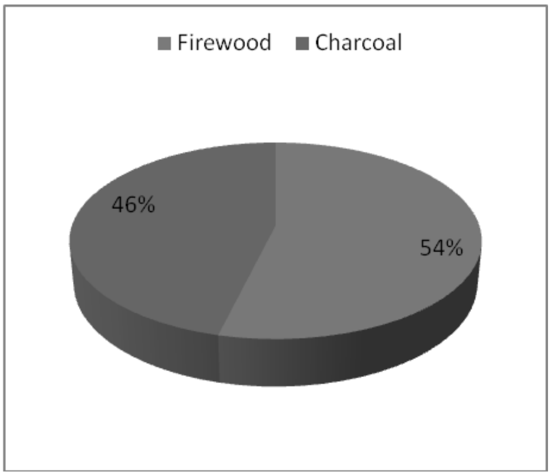

Figure 7. Commonly used energy sources in the institution

In addition to the choice of fuel, most of the institutions (72.7 %) use the traditional cooking stoves which consume large amounts of fuel wood while only 1 % uses improved stoves (Table 6). Most of the institutions indicated that, use of biomass energy contributes to over 30 % of the overall budget bill and that excludes other types of energy like electricity and generator expenses for lighting).

Table 6. Cooking devices used

Energy device	Frequency (n)	% frequency
Traditional stoves	8	72.7
Improved cook stoves	2	18.2
Solar cooker	1	9.0
Total	**11**	**100.0**

Frequency of collection and use of wood fuel types.

Majority of the respondents (85 %) indicated that fuel wood is procured and used throughout the year while charcoal is procured occasionally and used only at certain occasions and for specific meals like tea and rice which don’t require a lot of energy to cook.

Table 7. Frequency of collection and use of wood fuel types

Commonly used energy sources	Frequency (n)	% frequency
Collect firewood	1	7.7
Purchase firewood	7	53.8
Purchase charcoal	5	38.5
Total	**13**	**100.0**

Sources of the biomass fuels

Due to low tree resources in the area and within the institutions, most of the biomass energy used in the institutions is procured from the market (92.3 %) most of it coming from outside the Sub-County. Use of energy conservation technologies such as institutional energy saving stoves and establishment of wood fuel plantations within the institutions would reduce the amount and frequency of procuring biomass energy from the market and subsequently reduction in the overall budget bill (Table 8).

Table 8. Average Cost of energy per institution

Type of fuel	Average units /month	Average cost of one unit	Average cost of fuel per year	% contribution to institutional budget
Firewood	1(7tonne truck)	25,000	225,000	14 %
Charcoal	10	600	60,000	10 %
Total			**285,000**	**24 %**

Daily energy consumption by restaurants/eateries

Unlike households and institutions, most of the restaurants surveyed used alternative type of fuel like gas in addition to biomass energy for cooking and heating mostly light meals. The urgency in food preparation as required in restaurants requires that they have to use fuel that can light and cook fast when food is ordered unlike in institutions where timed schedules for food preparation are followed. Though more firewood sourced locally is consumed than charcoal, charcoal still contributes more to the overall energy bill compared to firewood because the cost of charcoal in the market is higher (Table 9). Thus there is need for increased adoption of energy saving stoves using firewood such as the modified brick stove or the rocket stoves for reduced energy consumption in eateries.

Table 9. Cost of energy source

Type of fuel	Average units /week	Average cost of one unit	Average cost of fuel per year	% contribution to institutional budget
Firewood	80	150	12,000	15 %
Charcoal	8	600	4,800	6 %
Gas	2	2,200	2,400	3 %
Total			**19,200**	**24 %**

Conclusions and Recommendations

From the study, increased exploitation and consumption of biomass energy using unsustainable stoves/ devices has greatly contributed increased energy bill both in households, institutions and eateries. This has translated to increased financial constraints or poverty at households' level and higher budgets in institutions and eateries. This calls for adoption of strategies that will reduce the amount of fuel purchased and used for cooking and heating, thus increased savings, less cutting of tree and environment conservation. The study recommends observation of energy saving tips like using energy saving stoves/technologies, exploring alternative cheaper fuels like briquettes which can be readily made from available agricultural residues like bagasse and lastly, it is important to undertake regular energy audits to determine areas of wastage in biomass energy use.

Acknowledgement

We sincerely thank KEFRI Management and the Green Economy Project (GEP) for logistical and financial support during the study and communities and institutions who participated in the study. The valuable inputs by the GEP field officers and the enumerators who assisted in data collection is dearly acknowledged.

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Appendix 1
ENERGY AUDIT CHART/ Tool (SAMPLE))

Type of fuel used	**Type of stove used**	**Type of food cooked**	**Average frequency of purchase/ week**	**Average quantity used per month**	**Average cost per unit**	**Average cost per month**	**% contribution to monthly bill**
Firewood							
Charcoal							
Gas							

Piloting Commercial Production of Charcoal Briquettes from Sugarcane Bagasse in Homa Bay County

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Abstract

Homa Bay County in the sugar belt of Kenya has only 3 % of the land covered by trees. About 75 % of the households in this county depend on wood from unsustainable forest resources for their energy needs. However, in Ndhiwa Sub-County, large volumes (about 3,000 tonnes per year) of sugarcane bagasse generated from Sukari Industries, one of the 12 sugar mills in Kenya remain unutilized. Inappropriate disposal of these residues emits greenhouse gasses (GHGs), responsible for global climate change. Besides, the communities living next to the mill face a number of challenges that include poverty, unemployment, food insecurity and lack of access to clean energy. In the Green Economy Partnership (GEP) project framework, three community-based bio-enterprise cooperatives have been set-up to produce and market carbonized biomass briquettes in Ndhiwa. High quality briquettes have been produced and are replacing wood charcoal and creating opportunities for jobs and poverty reduction. Important lessons from the cooperative business model have been learnt that are critical for up-scaling and replication of the technology in other areas of the country. Some key policy recommendations include: formalization of the feedstock supply plan with its suppliers and sugar millers; policy revisions to help eliminate identified challenges; optimization and strengthening of the briquette value chain to commercial operations; promotion of standardization and certification of biomass briquettes for wider market acceptability; promotion of information, research, technology development and transfer on biomass briquettes; enhancing partnerships and synergies including public-private partnerships for investments in briquetting and provision of tax incentives for briquette producers and equipment manufacturers.

Key words: Bagasse, Briquettes, Homa Bay, Ndhiwa, Kenya

Introduction

In the sugar belt of Ndhiwa Sub-County of Homa Bay County, with a population of 172,000 (CGH, 2013), at least 85 % of households depend on biomass fuel (charcoal and firewood) for their energy needs especially for cooking and heating (GEP, 2015).

Ndhiwa sub-county is amongst the remotest areas in the region, facing a number of socio-economic challenges (GEP, 2015). Poverty among the inhabitants is estimated at 60% as compared to the national average of 47 % (KNBS, 2010). The high level of poverty is exacerbated by lack of employment opportunities, food insecurity and a degrading environment with forest cover of 3 % (FAO, 2017) despite being home to a sugar processing mill which generates 126,148 million tons of bagasse each year (AFA-SD, 2016). Inappropriate disposal of bagasse emits greenhouse gasses (GHGs) such as methane, a dangerous gas responsible for global climate change (FAO, 2014). While turning bagasse into carbonised briquettes can help address challenges facing surrounding communities, technical, market, financial and policy barriers must be overcome.

A pilot project "Creating Green Local Economy through Commercial Production of Biomass Briquettes from Agro-Industrial Residues – 'Green Economy Partnership' (GEP, 2017) jointly implemented by Royal Norwegian Society for Development (Norges Vel), Kenya Forestry Research Institute (KEFRI) and Gum Arabic and Resins Association (GARA) financed by the Nordic Environment Finance Cooperation (NEFCO) targeted to address some of the challenges facing rural communities in Ndhiwa Sub-County.

The objective of the project was to develop the capacity of local enterprises in sustainable production and supply of carbonized biomass briquettes from sugarcane bagasse. The project aimed to support production of high quality briquettes using efficient carbonization and briquetting methods for thermal applications in households, local enterprises and institutions.

Materials and Methods

Project area

The project was implemented in 5 locations in Ndhiwa Sub-County covering five wards of Kanyadoto, Kanyikela, South Kabuoch, North Kabuoch and Kanyamwa. Ndhiwa is one of the eight sub-counties in the Homa Bay County located along the south west shore of Lake Victoria's Winam Gulf**.** Homa Bay borders five counties of Migori, Kisii, Nyamira, Kericho and Kisumu. The county consists of seven sub-counties namely; Mbita, Homa Bay Town, Rangwe, Karachuonyo, Kabondo, Kasipul, Suba and Ndhiwa (Figure 1).

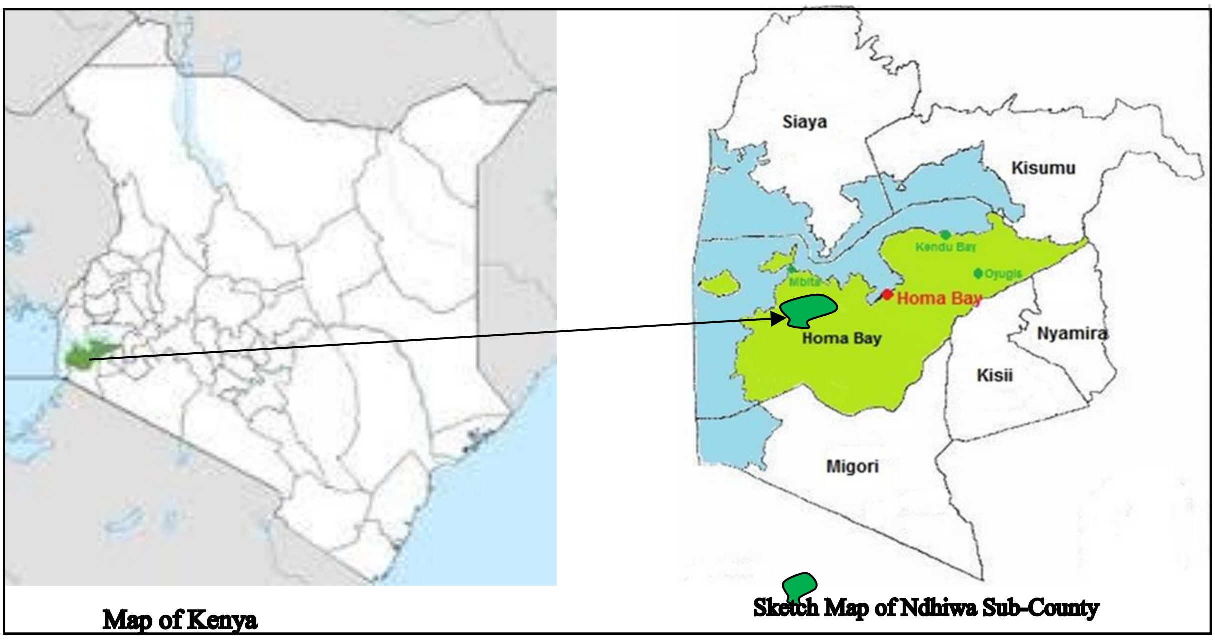

Figure 1. Map of project area

Population and economic activities in the project area

Ndhiwa Sub County has an area of 711.40 Km^2 and a population of 172,212 (KNBS, 2010). The communities in the project area are mainly involved in subsistence agriculture with sugarcane being the main cash crop. Sugarcane grown in the area is crushed at the Sukari Industry, a nearby private company. In addition, there are over 200 local jaggeries in operation which also provide a market for the sugarcane crop grown.

Methodology

This is a case study of a pilot project that used the cooperative business model as an approach to linking tested biomass carbonization and briquetting technology to private sector. It was implemented through three interlinked key tasks: sustainable briquette production, market analysis and development and advocacy. Sustainable briquette production focused on technology development, setting-up of pilot production enterprises and determination of optimal production parameters. Market analysis and development involved consumer surveys and establishment of distribution outlets. Business advocacy involved organizing farmers into cooperatives, mediating engagement with county government and private sugar millers.

Setting-up of community-based briquette micro-factories

As part of preparatory process, a series of stakeholder consultative meetings were held. After environmental impact assessment and licensing, layouts of 5 production units in five locations were set-up. A complete model of the recommended production line was developed (Figure 2).

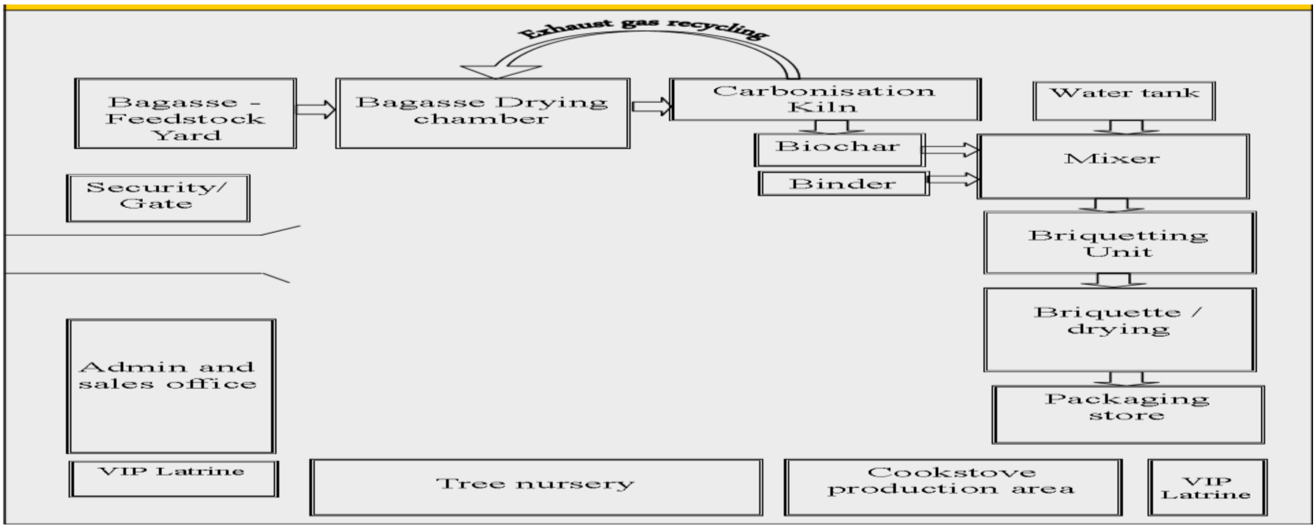

Figure 2. Schematic process flow of carbonized briquette production

Design and fabrication of dual-extruder screw briquetting machine

The project adopted a dual-extruder screw briquetting machine. The design was based on results of an evaluation of existing briquetting machines models. The first prototype with 10 horsepower (h.p) capacity was developed and installed at the first production site. This was subsequently modified with improvements to 15 h.p capacity (Table 1). Fabrication was done at Migori Engineering Facility by trained technicians with technical support from the project team.

Table 1. Specifications for improvement of briquette machine

S. No	Item	Description
1.	Motor	15 h.p geared, 3 phase
2.	Production capacity	1 tonne/day
3.	Finished product size	39 mm diameter
4.	Finished product shape	Cylindrical
5.	Raw material	Carbonized bagasse
6.	Screw length	24 inches
6.	Screw housing	4 inches cylindrical pipe diameter, 1.5 inches thickness
7.	Stand	Height 16 inches made of 2inch thick angle line metal.
8.	Electrical accessories	3 phase Electrical socket
9.	Pulleys and belt	Diameter of big pulley 375 mm, small pulley 125 mm, V belt with A cross section size B50
10.	Feed hopper	Same as KEFRI model
11.	Screw shaft	Length 32 inches and 1.5 inch diameter

Design and fabrication of carbonisation kiln

The carbonisation kiln was designed with two chambers: fireplace and carbonisation chamber (Figure 3). Fabrication and installation of carbonisation kiln, constructed of steel and insulated with fire bricks involved a series of testing and adjustments during the project period.

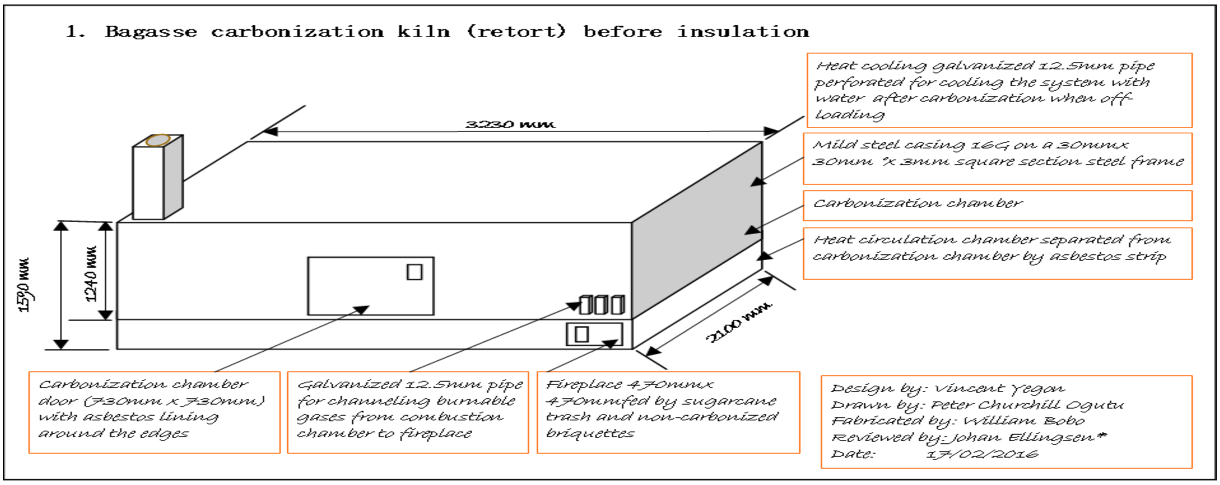

Figure 3. Sketch of bagasse biomass carbonization kiln

Development of feedstock supply plan

Feedstock survey was conducted among the two existing sugar mills and 50 local jaggeries mills. From cost analysis for gum arabic-based binder, a feedstock supply plan was developed through a consultative business planning workshop.

Technical and economic parameters

Required data on technical production parameters that would ensure best quality briquettes and determine the profitability of briquette production was collected using two methods. This involved observation and recording of input usage during briquette production test runs. Technical data capture forms were developed and used to record data on input (bagasse, binder, labour and power), production (biochar and briquettes) and sales. The daily data was summarized into weekly production reports by a trained production clerk. Bagasse briquette production facilities at Awendo and Muhoroni were also visited and informal discussions on drying and sales held with the operators. The data was then entered into SPSS software and analyzed.

Briquette product testing and evaluation

Samples of standard carbonized briquettes of size 32mm in diameter and 63.5mm long were obtained from Ligodho Briquette Factory. Thermal and emission laboratory tests were undertaken at KEFRI and Kenya Industrial Research Institute (KIRDI) laboratories using emissions analysers and Kenya Ceramic Jiko (KCJ). The tests were conducted in accordance with the WBT 4.2.2 (Guidelines for testing Charcoal Stoves) stove testing protocol and fuel analysis approach measured in an oxygen bomb calorimeter. Tests were meant to gauge the briquettes against known standards (South African), which included calorific values, ash content, volatile matter, fixed carbon content, emissions for $CO_{2,}$ CO, and particulate matter.

In order to test acceptance of carbonized bagasse briquettes, a consumer feedback survey was conducted among 199 households in 5 locations in Ndhiwa project area. Each household was provided with 5 kg of carbonised bagasse briquettes, 5kgs of charcoal from acacia trees

(*Acacia gerrardii*) and KCJ cook stoves. Each household used briquettes and charcoal to cook their normal meals for a period of 2 weeks, each energy product per week. Using follow-up forms, data was collected by enumerators for one week and was then coded and analysed.

Figure 4. Briquettes in 45-kg pack bags

Figure 5. Briquette testing in KCJ cookstove

Market analysis and potential for carbonized biomass briquettes

The study was conducted to analyse and understand biomass energy market situation in the project area, perception of consumers on biomass briquettes and to capture consumer willingness to shift to biomass briquettes as a source of energy. For energy efficiency, a simple guide (tool), determining energy consumption was developed and piloted to 50 households. Questionnaires were administered in 199 households, 10 schools and 10 eateries randomly selected. A total of 4 marketplace events and trade exhibitions were also held in Ligodho Market, Kendu-Bay, Eldoret and Kisumu. Data from consumer analysis, energy efficiency audit and marketplace events was entered into SPSS software and analysed.

Business development and policy, legislative and institutional frameworks

Rapid stakeholder mapping; engagement through consultative meetings with public and private sector actors were held. Formation of cooperatives involved community sensitisation, consultations and engagement with the responsible Ministry of Cooperatives. Advocacy efforts involved dialogue and consultative meetings, media engagement, awareness creation events, as well as advocacy training. Technology and knowledge transfer involved technical and skills training for adoption of biomass briquette technology and publications.

Results and Discussions

Key achievements of the pilot project was the establishment of 3 briquette production units in 3 locations, establishment of 5 bio-enterprise cooperative societies and capacity building in technical skills, business aspects and technology and knowledge transfer. The following (Figure 4) are key specific results achieved during the 30-month project period:

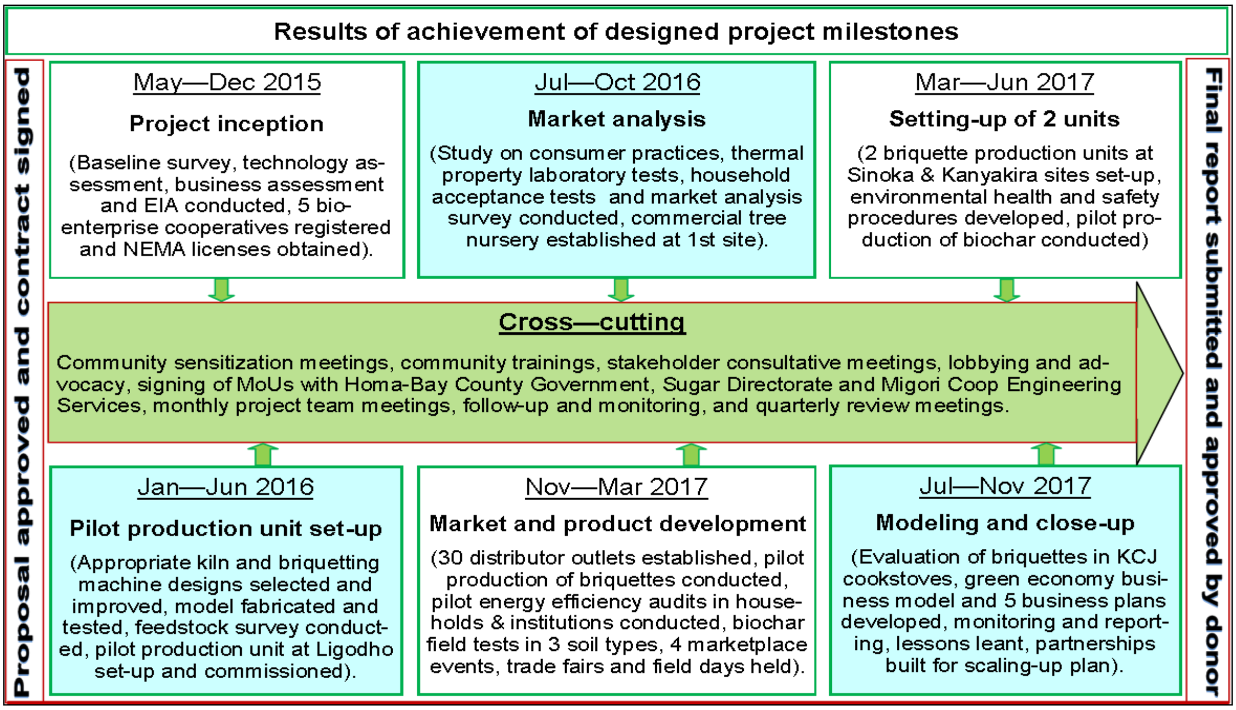

Figure 6. Results of achievement of designed project milestones

Setting-up of community-based briquette micro-factories

By the end of the project in Nov. 2017, three briquette production units had been set-up in three locations in Ndhiwa. Each unit had a complete production line comprised of carbonisation kiln, briquetting machine, feedstock yard, and a briquette drying area.

Biomass carbonization kiln

Four high efficient bagasse carbonisation kilns were installed at three briquette production sites (Picture 5). After modifications of the first two models, the final kiln had a capacity of converting 350 kg bagasse of 11-13 % moisture content into 75 kg biochar in 4-6 hours at a temperature of 320 ^{0}C. Kiln operators were trained to ensure the parameters were achieved.

Figure 7. Complete kiln in operation at Sinoka Bioenterprise factory

Figure 8. Former CS Environment Prof. Judy Wakhungu with operators at Briquette factory

Dual-extruder screw briquetting machine

Three 15h.p capacity briquette screw extruders were installed, each with a designed production capacity of 1 tonne of briquettes per 8-hour day operation (Picture 6). The high compaction technology consists of screw press. The biomass is extruded continuously by a screw through a taper die. In the process, briquette quality and production procedure is enhanced, achieving uniform and efficient combustion. Table 4 shows technical optimization parameters of complete production line at Ligodho Micro-factory.

Table 2: Overall analysis of feedstock needs (kgs)

	Year 1		Year 2		Year 3	
Cooperative	Gum arabic	Bagasse	Gum arabic	Bagasse	Gum arabic	Bagasse
Likabics	14,584	700,607	17,347	833,377	23,543	1,131,027
Sinoka	3,831	184,052	5,446	180,226	6,840	328,599
Kanyakira	3,889	702,819	9,056	435,074	11,480	551,508
Total	**22,304**	**1,587,478**	**31,849**	**1,448,677**	**41,863**	**2,011,134**

The three cooperatives have a combined total need of gum arabic of 22.30 tons, 31.85 tons and 41.86 tons and bagasse 1,587 tons, 1,449 tons and 2,011 for years 1, 2 and 3 respectively, Table 2. The results indicated that the co-operatives are assured of bagasse supply from either the two sugar factories or from the jaggeries. The supply of gum arabic is however highly vulnerable to other possible uses and hence the need to identify other suitable binding materials.

Analysis of feedstock needs for bio-enterprises

The main feedstock materials identified were sugarcane bagasse from nearby sugar mills, semi-processed bagasse from local jaggeries and gum arabic as the binder. Table 3 provides an analysis of feedstock needs for the three bio-enterprises over three years.

Figure 9. Sugarcane bagasse from sugar mill

Figure 10. Sugarcane waste from jaggery mills

Figure 11. Gum arabic – binder material

Table 3. Technical optimization parameters

Material	Parameter	Value
Production process type	Batch process hour/day	8
Bagasse sourced from Sukari Industries	Moisture content before drying (%)	51
	Moisture content after drying (%)	10-12
	Capacity (Kgs of dried bagasse/batch)	350
	Temperature (^oC)	320
Carbonization kiln	Carbonization ratio	4:1
	Duration in hours of carbonization – residence period depending on moisture content (hours)	4-6
Briquetting machine	Production capacity (Kgs wet briquettes per hour)	40
	Power rating (horsepower)	15
	Duration (Days)	2
Wet briquettes drying	Moisture content before drying (%)	16
	Moisture content after drying (%)	7-10
Mixing/formulation	1 kg gum arabic binder in 10 litres of water	1:10
	4 litres of the gum arabic solution is mixed with 5 kgs of carbonized material	4ltrs:5kg
	1 tonne of carbonized material requires 800 litres of water and 80 kgs of gum arabic.	1:800:80
Number of operators	Briquette machine	4
	Carbonization kiln	2
	Drying (bagasse and briquettes)	2

Analysis of production and impact on CO_2 emissions reduction

Actual production of biochar and briquettes in Ligodho, Sinoka, Kanyakira enterprises was done between June 2016 and Nov. 2017 (Table 4). Reduction of CO_2 emissions achieved was 7.7 tCO_2 from production units in a period of 17 months and a further 3,360 tCO_2 from 28,000 trees planted over a period of 24 months. The overall reduction of 33,709 tCO_2 is projected over 20 years.

Table 4. Summary of CO_2 effect of bagasse and biochar processed

Bioenterprise	No of employees	Bagasse received kgs	Biochar produced kgs	CO_2 subst. effect kgs	Biochar on stock kgs	CO_2 subst. effect kgs	Briquettes produced and sold kgs	CO_2 subst. effect kgs	Biochar sold to farmers kgs
Ligodho	7	54,759	8,994	16,189	3,985	7,173	4,259	7,666	750
Sinoka	5	20,040	2,300	4,140	1,800	3,240	0	0	500
Kanyakira	3	3,400	417	751	137	247	0	0	280
Total	**15**	**78,199**	**11,711**	**21,080**	**5,922**	**10,660**	**4,259**	**7,666**	**1,530**

Assumption: 1 ton briquette is estimated to replace 1.2 tons non-sustainable wood (1.5 t CO_2/ton wood)

Thermal characteristics of carbonized bagasse briquettes

Results from two laboratory tests done at the start of production and after adjustments of production parameters showed that the calorific values of the briquettes gradually improved from 4.5 kcal/g to 5.457 kcal/g (Table 5). The improved calorific value is well within the range of ordinary hard wood charcoal. However, the amount of particulate matter was noted to be high especially during the lighting up. The high ash content of 20% continued to be challenge. The indoor emissions though high are within limits permitted in Kenya.

Table 5. Laboratory test results on bagasse briquettes using gum arabic as binder

Parameter	Test 1	Test 2
Gross calorific value	4.3kcal/g	5.457kcal/g
Moisture content	10.0%	5.9%
Ignition time	-	4min
Time to boil 5L	-	34min
Glowing time	-	164min
Charcoal consumed	-	424g
High power burning rate	-	6.97g/min
Low power burning rate	-	1.68g/min
Ash remaining	-	86g
Ash content	24g	20g
High power thermal efficiency	-	32.3%
Low power specific consumption rate	-	0.010MJ/min/L
High power CO	-	23.88g/MJd
Low power CO	-	0.14g/min/L
High power PM	-	153.2mg/MJd

Parameter	Test 1	Test 2
Low power PM	-	1.6mg/min/L
Indoor emissions CO	-	1.11g/min
Indoor emissions PM	-	7.1mg/min

Consumer acceptability test of carbonized briquettes in households

From results of household acceptability test for applications for cooking, carbonized briquettes and wood charcoal from acacia tree exhibited different characteristics (Figure 6).

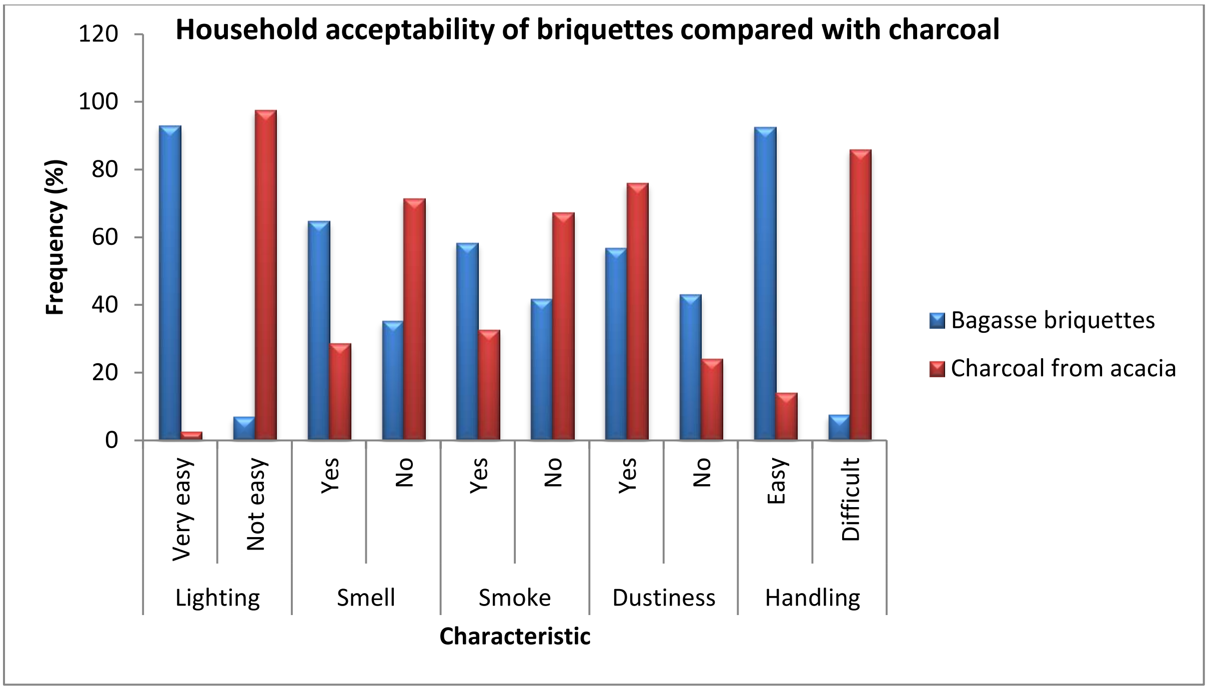

Figure 12. Characteristics of briquettes and charcoal for household use

Majority of the respondents (93 %) found briquettes very easy to light while 55.8 % of the respondents rated charcoal as being moderately easy to light. On smell, 64.8 % of the respondents said briquettes produced smell against 35.2 %. About 71.4% of the respondents said charcoal had no smell compared to 28.6 % who reported some irritating smell. About 58.3% of respondents said briquettes produced smoke in the lighting stage, whereas 67.3% said charcoal did not. On application, majority of the respondents (92.5 %) felt the briquettes were of medium size and easy to handle and (56.8 %) found them moderately dusty. However, 85.9 % of the respondents felt the charcoal, was of big size and difficult to handle with 75.9 % found them very dusty. For the various type of food cooked by households, an average amount of a 2kg tin of briquettes required was 2.0 and that of charcoal was 1.8.

From the results, for consumers, a type of energy source which is faster to light is preferred. However, a smelly, smoky or dusty energy source can be a deterrent to its use and preference by consumers. Smell, smokiness and dustiness can be attributed to use of materials which are not completely carbonized, type of materials and binder used. Consumers prefer use of energy source which is cheaper that would save the family financial resources.

Market analysis and potential for carbonized biomass briquettes

Results from market analysis showed the current energy utilization levels in Ndhiwa project area as shown (Figure 13) are households and (Figure 14) restaurants and institutions. For households, firewood (84.8 %) was identified as the most common energy source for cooking followed by charcoal (11.2 %). Others included paraffin, crop residue and gas.

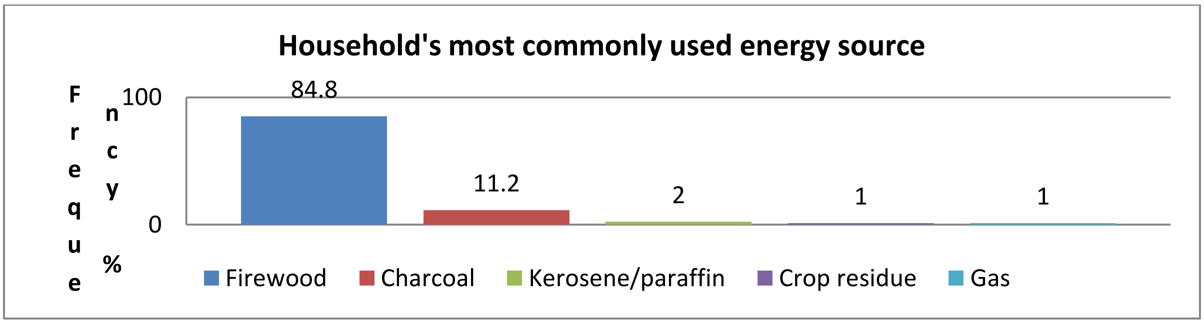

Figure 12. Household's most preferred energy sources

Of 23 restaurants with a daily average of 170 customers interviewed, the most preferred sources of energy (Figure 5) were charcoal (65.2 %), firewood (30.4 %) and gas (4.4 %).

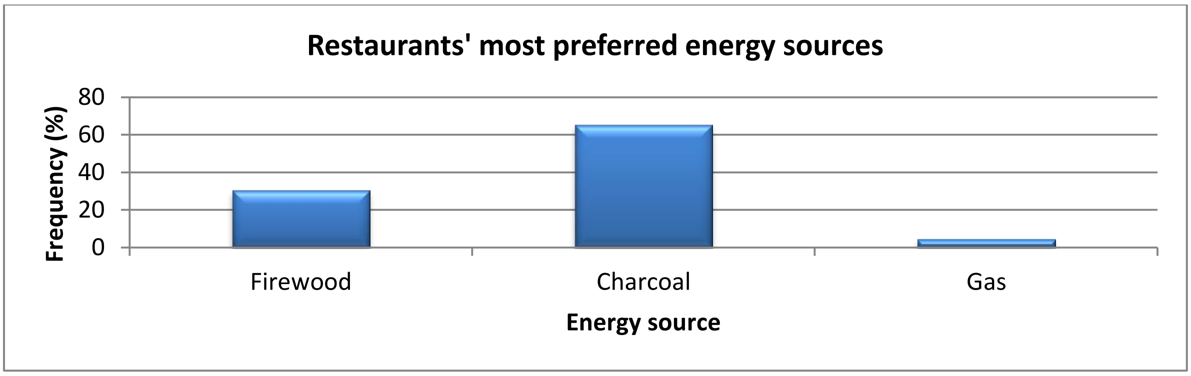

Figure 13. Energy sources most preferred Restaurants

Traditional three stones (64 %) and KCJ (32 %) were most common types of stoves used. Results from focused group discussions revealed worsening accessibility for firewood and charcoal in the next five years and that plantation sugarcane farming practice in the region has led to rapid decline in tree density. On alternative sources of biomass energy, only about 30% of respondents revealed that they have some little information about briquettes. The fact that households and businesses are finding it hard to access firewood and charcoal suggests that there are currently unmet energy needs and hence briquettes have potential to bridge the gap.

Business modeling and economic analysis

Results of financial analysis indicate that within 17 months, a total of 4.3 tonnes of carbonized briquettes, 1.53 tonnes of biochar soil improver and 18,840 tree seedlings had been sold by first production unit. The total income generated was KES 219,356 with a net profit of KES 25,106 (Table 6). However, the low production was as a result of challenges including machine modifications and long shut-down times due to frequent power outages. The sales are guaranteed so long as production meets the market demands. Both briquettes and tree seedlings are sold as soon as they are produced.

Table 6. Financial analysis

Product	Price (KES)	Amount sold	Total (KES)
Revenues			
95 bags Briquettes (800 KES/bag)	800	95	75,716
Biochar sold to farmers (KES/kg)	20	1,530	30,600
Trees (KES/each)	6	18,840	113,040
Total (KES)			**219,356**
Cost			
Cost of production of briquettes/ton (KES 30/kg)	30,000	95	128,250
Cost of production/tree seedling	2	28,000	56,000
Total (KES)			**184,250**
Net profit			**25,106**
Assumption:	1 briquette has the weight of: 1000 grams/35 = 28,7 grams		

Policy advocacy and associations

5 cooperative societies were formally registered, trained and linkages formed to manage the briquette production units through consultation and engagement with Ministry of Cooperatives. They also participated in market systems and continue to improve the livelihood of their members. A total of 30 local traders were trained as briquette distributors, while 9 were trained in carbonisation and briquette production. The concept received overwhelming support from community, county and national governments, private sector, and mainstream media. However, key infrastructure i.e. stable electricity supply, all weather road networks, markets and access to feedstock remain the main challenges to sustainability of the production units.

Conclusion

Key achievements of the pilot project were the establishment of 3 briquette production units in 3 locations, establishment of 5 bio-enterprise cooperative societies, capacity building in technical skills, business aspects and technology and knowledge transfer. In regard to climate change mitigation, a total of 7.7 tCO_2 had been reduced from production units and a further 3,360 tCO_2 through the trees planted with projected overall reduction of 33,709 tCO_2 over 20 years. Although the project target of establishing 5 production units was not fully realized due to unforeseen challenges, the concept demonstrated opportunities for addressing multiple challenges facing smallholder sugarcane farming communities. However, sustainability of the pilot production units is subject to: i) formalisation of agreements for access to sugarcane bagasse or alternative biomass feedstock, ii) stability of power supply in the region and optimisation of production processes to achieve commercial operations and; iii) streamlining of open and ethical biomass energy markets including implementation of charcoal rules (regulations), product standardisation and certification. Potential partnerships with county government, sugar directorate, other non-governmental organisations (NGOs) and private sector provide possibility for scaling up and replication of the business model.

Lessons learnt

The innovativeness of this project was both on the briquette production side and the marketing side. Briquette production focused on turning sugarcane bagasse, into carbonized briquettes to replace charcoal for cooking and heating. The briquette production line including an efficient carbonization kiln system and briquette production machine has been innovative in regard to technology adoption by local engineering enterprises through skills training and mentorship. The project has provided a technology transfer pathway by linking tested technology to the industry, especially the micro- and small enterprises in the renewable energy value chain.

The cooperative model has been an innovative market-led approach to creating awareness of carbonized briquettes, a new energy product in the region and in engaging local communities of both genders in product distribution. This had made it possible for biomass energy consumers to switch to briquettes from wood based energy for their cooking and heating.

The concept of green economy partnership has demonstrated opportunities to solve identified challenges in community, country and global contexts. Even though all the targets were not achieved, the project is an eye-opener on new ways of addressing challenges connected to climate change. The project has been implemented with strong human resource, networks and team work, which is a cornerstone for change. The cooperatives established have demonstrated energy and openness with solid support from the communities, county and national governments, critical for scaling-up and replication of the concept.

Trials conducted on various aspects of the technology and processes in briquettes value chain are important for improving the system (kiln and briquetting machine) and logistical processes of feedstock acquisition (biomass raw material and binders) is therefore possible.

Challenges and opportunities that emerged are important for further research and development, capacity building and innovations for alternatives and solutions. Although legal confirmation of availability of sugarcane bagasse by a private sugar miller has not be realized, engagement with actors in public and private sector including the Sugar Directorate has reinforced the need for policy intervention in the agro-industry in Kenya and mapping of alternative feedstock resources such as local jaggery mills, maize cobs and groundnut shells.

Successful cooperatives are those with a good gender balance or led by women or dominated by women, in the key areas of decision-making processes and in program implementation. The project was implemented with strong gender consideration as an important component in empowering and employment in the transfer of skills and knowledge, decision-making structures and distribution of benefits. The three cooperatives have shown a clear gender balance in the composition. People need time to change and build networks. It was noted that although the project was well-anchored in Kenya's Vision 2030, the plan was too optimistic with regard to time schedule, volume and value needed to change people's attitude and habits towards briquette use.

Recommendations

1: There is need to review and lobby for improved policy and legislative framework conditions including provision necessary infrastructure (roads, electricity and markets) for development of sustainable briquette enterprises within the sugar commodity value chains.

2: Link community-based briquette enterprises with public and private sugar millers and suppliers and formalize contractual agreements for guaranteed availability of bagasse.

3: In order to meet the increasing market demand, there is need to support optimization of production, efficiency and logistical systems of pilot briquette factories to achieve best cost/performance parameters for commercial-scale operations and economic viability.

4: To enhance safety, ethical business practices and product quality improvement and marketability in compliance with international standards and based on the demonstrated results, there is need to develop and register standards, protocols and guidelines for production and use of carbonized briquettes from sugarcane bagasse.

5: From the results of the project studies, some critical information for scaling-up has been confirmed. However, given the limited scope of these studies, there is a need for reviewing available information on the impact on livelihoods and that additional data on the relation between decline in tree cover and demand for fuel wood in the area be established.

Acknowledgement

This case study was under the project "Creating Green Local Economy through Commercial Production of Biomass Briquettes from Agro-Industrial Residues in Kenya – Green Economy Partnership (GEP)" implemented by Kenya Forestry Research Institute (KEFRI) in partnership with Gum Arabic and Resins Association (GARA) and Royal Norwegian Society for Development (Norges Vel). The authors would like to thank all those who were involved in successful completion of the project. Particular thanks go to the Nordic Climate Facility (NCF) for the grant and technical support. The authors thank Sikko, Kari, and Johan, Jorunn, Bobo, and community based bioenterprises including John Odull, Beatrice Ageng'a. Data on thermal qualities obtained from KEFRI (Nathan Nyamai) and KIRDI.

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Priority Non-Wood Forest Products in Cherang'any Hills Ecosystem

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Abstract

Cherang'any forest is one of Kenya's five main water towers and is one of the water towers that the Kenya's Water Tower Protection and Climate Change Mitigation and Adaptation (WaTER) programme aims at raising community appreciation of natural forest areas through the promotion of sustainable utilization of non-wood forest products (NWFPs) from the forest. This is however hindered very scanty information on NWFPs in Ecosystem. In order to bridge the gap, the programme conducted a baseline survey of key non- wood forest products (NWFPs) of socio-economic importance in Cherang'any forest ecosystem. The survey was done by administrating semi-structured questionnaires on 266 randomly selected respondents and conducting focused group and key-informant interviews. The data was analysed for descriptive statistics using SPSS. The survey revealed that: 98% of the respondents collected, utilized or sold to neighbours, the NWFPs that were collected in large quantities included roots and tubers, indigenous fruits, fodder and gums and saps (annual per capita collection ranged between 19 – 80 Kg). Households earned up to KES 66,000 and KES 50,000 from sales of honey and other NWFPs respectively in 2016. It can therefore be concluded that NWFPs play a significant role in the day to day livelihoods of the communities living adjacent to Cherang'any ecosystem and have a potential of reducing poverty level. The earning from the NWFPs and therefore appreciation of the forest by the community can be enhanced through the sustainable commercialization of fodder, roots and tubers, indigenous fruits, gums and saps, vegetables, medicine, and honey.

Key words: NWFPs, Utilization, earnings, Cherang'any forest.

Introduction

As a consequence of short term livelihood activities with often negative downstream externalities, communities adjacent to forests will rarely have the ability to sustain Kenya's forested landscapes that provide critical ecosystem services. It is in line with this that the Kenya's Water Tower Protection and Climate Change Mitigation and Adaptation (WaTER) Programme pursues innovative institutional approaches for linking ecosystem services providers and beneficiaries through the design and implementation of rewards and/or payments for ecosystem services.

The Kenya's Water Tower Protection and Climate Change Mitigation and Adaptation (WaTER) Programme, is a programme funded by the European Union and being implemented by KEFRI alongside other partners. The overall objective of the programme is to contribute to poverty reduction and sustainable livelihoods by applying scientific principles to inform design of community level actions and national policy decisions on rehabilitation and conservation in Cherang'any and Mt. Elgon water towers. Under component 4 of this programme, KEFRI is working with key organizations including the Kenya Forest Service (KFS), Kenya Wildlife Service (KWS), the Kenya Water Towers Agency (KWTA) and the 11 participating County Governments. The goal is to improve the management of Mt. Elgon and Cherang'any forest ecosystems which are key in the management of western Kenya water resources. These two forest ecosystems are part of the Kenya's five "Water Towers" and therefore important for water catchment.

One of the expected results of the programme (ER 3) is: ***Integration of selected rehabilitation and conservation technologies for improved Natural Resource Management, Sustainable Land Management and Agricultural Water Management in the 2 water towers demonstrated.*** This objective seeks to leverage integrated natural resource management technologies to improve the rehabilitation and conservation of the water towers catchments. One of the efforts to raise community appreciation of natural forest areas would involve the promotion of sustainable utilization of non-wood forest products (NWFPs) around the project areas.

Non-wood forest products (NWFPs) are goods of biological origin other than wood, derived from forests, other wooded land and trees outside forests (FAO, 1999). They are major sources of food, medicines, fodder, gums, resins, fibre, cosmetic and cultural products. Currently, there is high and increasing global demand for bio-products and nutraceuticals derived from NWFPs. Global market for medicinal plants, for instance, is estimated at over USD 14 billion/yr. The importance of NWFPs for rural households, particularly in times of adversity, is well documented (Shackleton *et al.*, 2007, Jama *et al.*, 2008). With the exception of medicinal plants used by herbalists in Elgeyo Marakwet County, whose information was documented by Kipkore *et al.*, 2014, there is very scanty information on other NWFPs in Ecosystem. In order to provide additional information on NWFPs in the forest, the programme therefore examined the existing indigenous technical knowledge and conducted baseline survey socio-economic surveys targeting NWFPs with commercial value. The generated information was expected to strengthen the available local knowledge and provide critical baseline information for the development of the sub-sector. Furthermore, the generated information would also contribute to the improvement of these products; enhance their sustainable production through their domestication and natural regeneration; improve market access and linkages for the products; contribute to the development of enabling policy, institutional and regulatory frameworks for the products. It is desired that the local people would apply the information to diversify their incomes and improve their livelihoods through sustainable commercialization of prioritised and viable products.

The overall objective of the study was to undertake a baseline survey of key non- wood forest products (NWFPs) of socio-economic importance in Cherang'any forest ecosystems and had the following specific objectives:

1. To obtain information on key sources of livelihood
2. To identify and rank the key non-wood forest products in the ecosystem
3. To assess participation of the community in environmental conservation activities

Materials and Methods

Sampling of respondents

The study was carried out by a team of KEFRI Scientists and Project staff in collaboration with local stakeholders. A desk review on NWFPs in the study areas was done and the lessons learned from previous studies, opportunities and gaps documented. Semi-structured questionnaire(s) were used by trained enumerators to obtain information from selected households. The team used multi-stage stratified purposive sampling procedures to select appropriate households and villages. Firstly, Forests stations were purposively selected to reflect three different agro-ecological zones (high, high medium and low medium). One forest block was then selected from each station. In the third stage, three villages were purposively selected from each block using altitude of the village as the criterion of selection. Finally, 10 households were randomly selected from each village. The selected forest stations included Chemukoi, Kipteberr, Kapolet, Koisungur, Kapkanyur, Sogokio and Toropket.

A total of 266 questionnaires were administered to households living adjacent to the different forest blocks in the ecosystem. Among other variables, the questionnaire was design to measure the following indicators: Household profile, land ownership; key sources of livelihood and key non-wood forest products in the ecosystem. Focus group discussions and key informant interviews were held to verify and validate some of the information generated from the questionnaires.

One Focused Group Discussions (FGD) was held for the three selected villages per forest block and as 2 key informant interviews (KII) were conducted in the County. The FGD and KII questionnaires were developed to address the following key issues related to NWFPs:

- Availability, sources, production, harvesting, processing, sustainability and marketing
- Resource and conflict management including indigenous rules and regulations
- Strategies for sustainable utilization of the resources
- Key stakeholders in the value chain
- Capacity building and community participation
- Key challenges and opportunities
- Social services, infrastructure

Data organization and analysis

To ensure data and procedural quality control, strict supervision, guidance and backstopping were done by the team members. The training of data entry clerks emphasized the importance of care and attention to detail in coding and data entry. Coding was done based on forest block and categories of NWFPs and responses. The data was entered in MS Excel spread sheets. Further data cleaning was done on the completed data sets prior to analysis. Analysis of the baseline survey data was carried out using SPSS (21) and MS Excel. Quantitative data was analysed for proportions, frequencies and means. Qualitative data synthesis and analysis techniques largely involved systematic synthesis, or putting the material collected into a narrative account of the availability and utilization of NWFPs. In order to translate the local names of indigenous fruits and vegetables into scientific and/or common name, the team used the work of Maundu *et al*., (1999) and relied on expert advice too.

Study site description

Cherang'any Forest sits astride the watershed between the Lake Victoria and Lake Turkana basins. Spatially, Cherang'any Hills is 35° 26" East and 1°16" North at an altitude range of 2000-3365m above sea level (Republic of Kenya 2015-2015). Cherang'any Hills forest ecosystem comprises of 12 forest blocks, cutting across three counties, Trans-Nzoia, Elgeyo Marakwet and West Pokot, on the Western ridge of the Great Rift Valley. It covers an area of 120,000 ha, forming the upper catchment of Nzoia, Kerio and Turkwel rivers (KFWG and DRSRS, 2004). The watershed not only underpins livelihoods of communities within Lakes Victoria and Turkana Basins, but stretches its significance to national and global capacity. However, this ecosystem has never been an exemption to anthropogenic disturbances of land use pressure, demographic characteristics and even climate change (Republic of Kenya 2015). The least affected forests are those on the Cherang'any hills with only 174.3 hectares deforested. However, this loss is occurring in indigenous forest cover (KFWG and DRSRS, 2004). The Cherang'any Hills are largely covered by a series of indigenous forests and made of 13 forest blocks; Kapolet, Kapkanyar, Kiptaber, Sogotio, Chemurkoi, Kaisungur, Kerrer, Embobut, Kipkunur, Lelan, Toropket, Cheboi and Kapchetumwa. The total gazetted area is 95,600 ha, out of this, 60,500 ha is closed canopy forest, the remainder being formations of bamboo, scrub, rock, grassland, moorland or heath, with 4,000 ha of cultivation and plantations. The maps showing Cherang'any Forest Ecosystem and the sampling sites are shown in Figures 1 and 2 respectively.

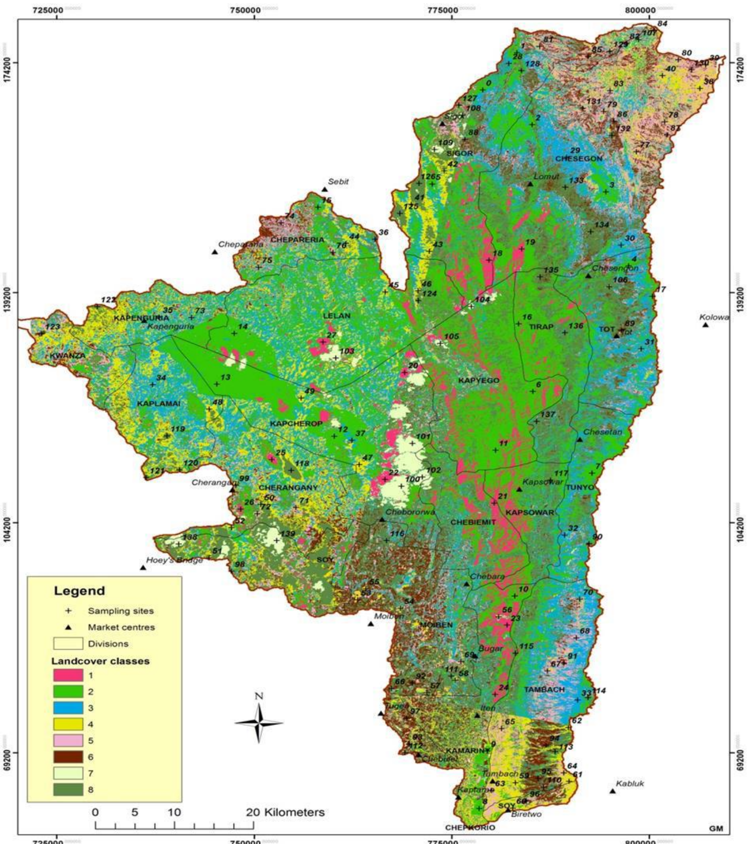

Figure 1. Cherang'any Ecosystem Land Cover Map (Source; KEFRI Land Use Land Cover Report-2016)

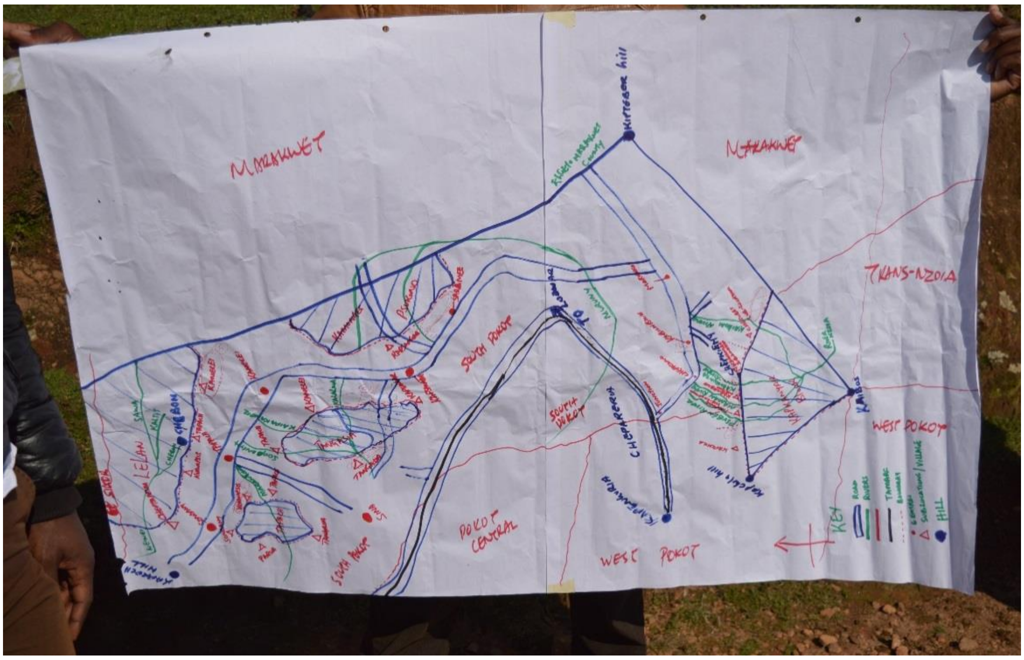

Figure 2. Sketch of sampled areas

Results and discussion

Respondent characterization

Table 1. Socio economic characterization of the respondents

Demographic characteristics	**Frequency (%, n = 266)**
Gender	
Female	25
Male	75
Age class of household head (in years)	
< 25	6.0
25-34	21.1
35-44	24.8
45-54	19.2
55-64	12.8
65-74	12.0
>74	4.1
Marital status	
Married	89.8
Widow/widower	4.9
Single	3.8
Divorced/separated	1.5
Education level of household head	
Illiterate	7.2
Basic (can read and write)	20.5
Primary	46.2
Vocational	0.4
Secondary	19.7
Tetiary (college and University)	6.1
	Means
Size of household	7 persons
Years lived in area	31.9 year
Distance of homestead to the forest edge	1.7 Kilometres

Seventy-five (75) percent of the respondents were male and twenty-five (25) percent female. About 90% of the respondents were married with the remaining percent were either single, widowed or divorced (Table 1). Slightly less than 50% of the heads of households and about 20% of the heads had primary and secondary education respectively. Illiterate households' heads were 7.2 % (Table 1). This implies that vast majority of the households are literate. Majority of the respondents were married (89.8%), followed by widows/widowers. The least number was the divorced/ seperated at 1.5% as shown in Table 1. The respondents had an average household size of 7 persons and the heads of household had lived in the locality an average of 31.9 years. The mean age of the head of household was 45.8 years with 25 – 54 years being most frequent age brackets accounting for about 65% of the households (Table 1). The distance of the homesteads from the forest edge was on 1.7 km.

Resource endowment of households in Cherang'any Hills Forest

Table 2. Households' resource endowment in Cherang'any Hills Forest

Resource endowment	**Mean**
Size of household	7 persons
Size of land	2.26 hectare
Livestock Ownership	**Mean number**
Shoats	9
Poultry	6
Cattle	4
Pigs	3
Donkey	2

Source of household income	**Frequency (%)**	**Mean household annual income (KES)**
Crop farming	81.6	78,923
Livestock farming	4.1	58,124
Business income	5.6	95,500
Wages and salary	6.8	39,228
Casual work	1.1	Not available
Bee keeping	-	14,890
NWFP	-	7,729

The mean landownership was 2.26 hectares, and the households had on average, 9 shoats, 6 poultry, 4 cows, 3 pigs and 2 donkeys (Table 2). About 82% of the households relied on crop farming as the major source of income. Other major sources mentioned included livestock rearing, casual jobs, salaried jobs and self-employment/business (Table 2). The survey found that highest annual earning was from wages and salary at KES 95,500 while earning from NWFP was lowest at KES. 7,729 (Table 2).

Utilization of NWFPs by the Community
Respondents' opinion on availability of NWFPs

Table 3. Respondents' perception on availability of NWFPs

	Respondents' perception on availability		
NWFP	**Easily**	**Moderately**	**Unavailable**
Medicine	43.2	47.9	8.9
Mushrooms	22.4	55.6	22.0
Ropes	55.4	41.8	2.7
Honey	21.5	54.7	23.8
Vegetables	48.7	46.7	4.5
Exotic fruits	41.0	53.2	5.8
Bush meat	31.8	33.5	34.7
Cosmetics	61.8	32.2	6.0
Roots and tubers	44.4	33.3	22.2
Gums and saps	27.4	56.5	16.1
Indigenous Fruits	58.7	39.7	1.5
Fodder	51.8	42.4	5.9
Dyes	0.0	100.0	0.0
Aloe	47.4	28.9	23.7
Medicine	43.2	47.9	8.9

Cosmetics, ropes, indigenous fruits, and fodder were considered easily available by more than 50% of the respondents. All the above listed NWFPs were considered between moderately to easily available by at least 75% of the respondents. About 20% of the respondents were of the opinion that mushrooms, honey, bush meat, root and tubers, and aloes were difficult to get (Table 3).

Usage and sales of NWFPs in Cherang'any

Table 4. Utilization of the NWFPs

Non-wood forest product	Total quantity collected (in Kg)	Quantity used (Kg)	Quantity sold (Kg)	Quantity as % of collected amount	Price per unit
Medicine	6.1	5.1	1.0	16.4	9.0
Mushrooms	13.3	11.0	2.3	17.3	
Ropes	6.6	5.4	1.2	18.2	
Honey	3.2	2.8	0.4	12.5	460.6
Vegetables	4.1	3.8	0.3	7.3	
Exotic fruits	12.4	7.6	4.8	38.7	127.6
Bush meat	10.0	8.5	1.5	15.0	
Cosmetics	6.3	6.0	0.3	4.8	
Roots and tubers	80.3	23.1	57.1	71.1	5.0
Gums and saps	18.9	3.0	15.9	84.1	
Indigenous fruits	25.1	17.6	7.5	29.9	100.2
Fodder	21.6	17.5	4.0	18.5	1.0
Dyes	2.0	2.0	0.0	0.0	
Aloe	2.4	2.3	0.1	4.2	

With the exception of dyes, a surplus was sold for all the other products. It was however only for indigenous fruits, exotic fruits, roots and tubers, gums and saps a proportion of 30% or greater that was sold (Table 4). The major market outlet for all the NWFPs was direct sales to consumers with only honey and with only exotic fruits being sold in to rural assemblers, middlemen and exporters in small quantities.

Earnings from NWFPs

The average income from honey production and other NWFPs ranged from KES 500 to KES 66,000. Across all the blocks, the income from honey production was higher than from the other NWFPs. The income from NWFPs was highest in Toropket block and lowest in Sogotio block (table v, figure 3). The number of households relying on the NWFPs ranged from 1 to 6 per block. This results suggests that honey, is the NWFP of choice for income creation and it has the highest potential Toropket block.\

Table 5. Annual household income from NWFPs in Cherang'any

Forest block	Source of income	Average annual income (KES)	Frequency (n)
Toropket	Bee keeping	66,000.00	3
	Other NWFPs	50,000.00	1
Sogotio	Bee keeping	4,666.67	3
	Other NWFPs	500.00	1
Kipteber	Bee keeping	1,125.00	2
	Other NWFPs	1.000.00	2
Chemurkoi	Bee keeping	13750.00	4
	Other NWFPs	800.00	2
Kapolet	Bee keeping	12,333.33	6
Koisungur	Bee keeping	2,333.33	3
	Other NWFPs	0.00	1
Kapkanyar	Bee keeping	5,500.00	4

Collection of NWFPs as per gender

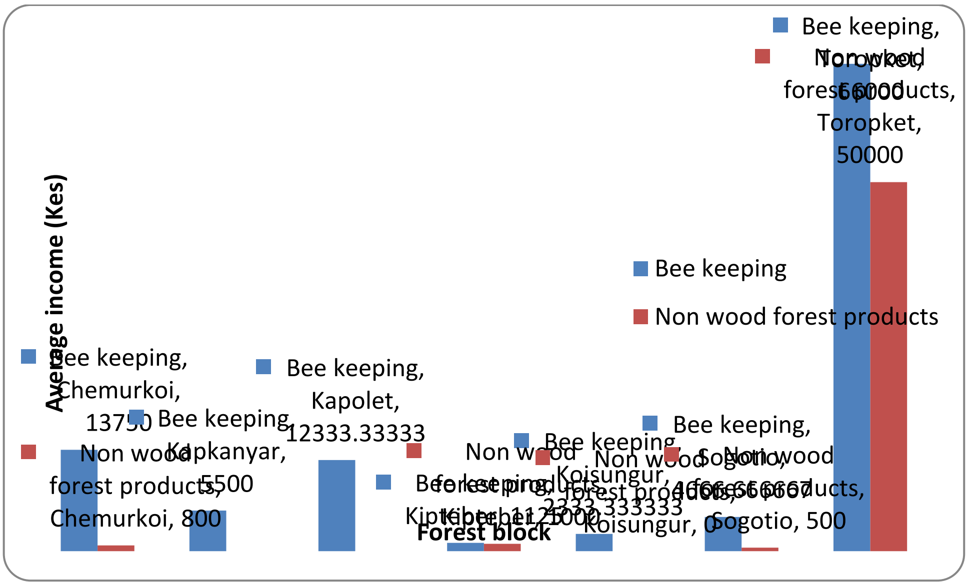

Figure 3. Annual incomes from NWFPs per block

Table 6. Collection of NWFPs as per gender (Person responsible for collecting)

	Equally distributed among household members	Equally distributed between adults	Mainly male adults	Mainly female adults	Equally distributed between children	Mainly boy	Mainly girl
Medicine	XX	XXX	X	X			
Mushrooms	XX	X	X	XXX			
Ropes	XXX		XX	X			
Honey		X	XXXX				
Vegetables	X	XX		XXX			
Exotic fruits	XXXX				X		
Bush meat	X		XXXX				
Cosmetics	XX	XX	X	X			
Roots and tubers	XXX			XX	XX		
Gums and saps	XX	X	X		XX		
Indigenous fruits	XX				XXX		
Resins	XX	X		X		X	
Fodder	XX	XX	XX				
Dyes		XXX		XXX			
Aloe	XXXX	XX					

Key

Adult is > 15 years

Child is < 15 years

X means in 10 – 20 % of the households,

XX means in 21 – 40 % of the household

XXX means in 41 – 60 % of the households

XXXX means in > 60% of the household

Table 7. Summary of responsible gender for collection of NWFPs

NWFPs	Responsible gender
Medicine	Both adult females and males, all members
Mushrooms	Adult female, all members of the household
Ropes	All members of the household, adult male
Honey	Adult male
Vegetables	Adult female
Exotic fruits	All members of the household
Bush meat	Adult male
Cosmetics	All members of the household, adult male and female
Roots and tubers	All members of the household, boys and girls
Gums and saps	All members of the household, boys and girls
Indigenous	Boys and girls, all members of the household
Resins	All members of the household, employed persons, boys
Fodder	All members of the family
Dyes	All members of the family, adult male and female
Aloe	All members of the family

With the exception of vegetables, honey and bush-meat, harvesting of the other NWFPs was in general the joint responsibility of all household members in more than 10% of the households with harvesting of exotic fruits and aloes being greater than 60% of the households. Harvesting of honey and bush-meat was the responsibility of adult male in greater than 60 percent of the households while vegetables and mushrooms was the responsibility of the adult female in greater than 40% of the households (Tables 6 and 7)

Detailed information on available NWFPs in Cherang'any Forest

Indigenous fruits

A total of 40 indigenous fruits were named by the respondents. The ten most known fruits by the respondents were; Lamai (*Syzgium guinense*), Monmoon (*Rubus pinnatus*), Mendililwa (*Dovyalis abyssinica*), Siryowo (*Rhus natalensis*), Tangururuo (*Flacourtia indica*), Simat (*Ficas thonningli*), Siriekwo, Losiek, Kimolon and Mokoi/Cheptolong/Mboni (Table 8, Figure 4). A vast majority (> 70 percent) were of the opinion that fruits were abundant (Table 8). Apart from the indigenous fruits the following exotic fruits were also mentioned by the respondents and are available in varying quantities: passion, avocado, tree tomato, guavas, loquats.

Table 8. Awareness and abundance of indigenous fruits in Cherang'any Hills Forest

Local name	Scientific name	Proportion of respondents aware of the fruit (in %, n = 266)	Proportion of respondents perceiving fruits as abundant (in %)	Other Uses
Lamai	*Syzgium guinense*	77	93	
Monmoon	*Rubus pinnatus*	64	90	Medicinal
Mendililwa	*Dovyalis abyssinica*	29	89	Medicinal
Tungururwa	*Flacourtia indica*	9	90	
Simat	*Ficas thonningli*	7	72	
Mokoi/Cheptolong/Mboni		35	87	
Siriekwo		32	86	
Losiek		30	91	Vitamin, Helps In Digestion
Kimolon		17	86	Food Additive
Siryowo	*Rhus natalensis*	12	71	Medicinal

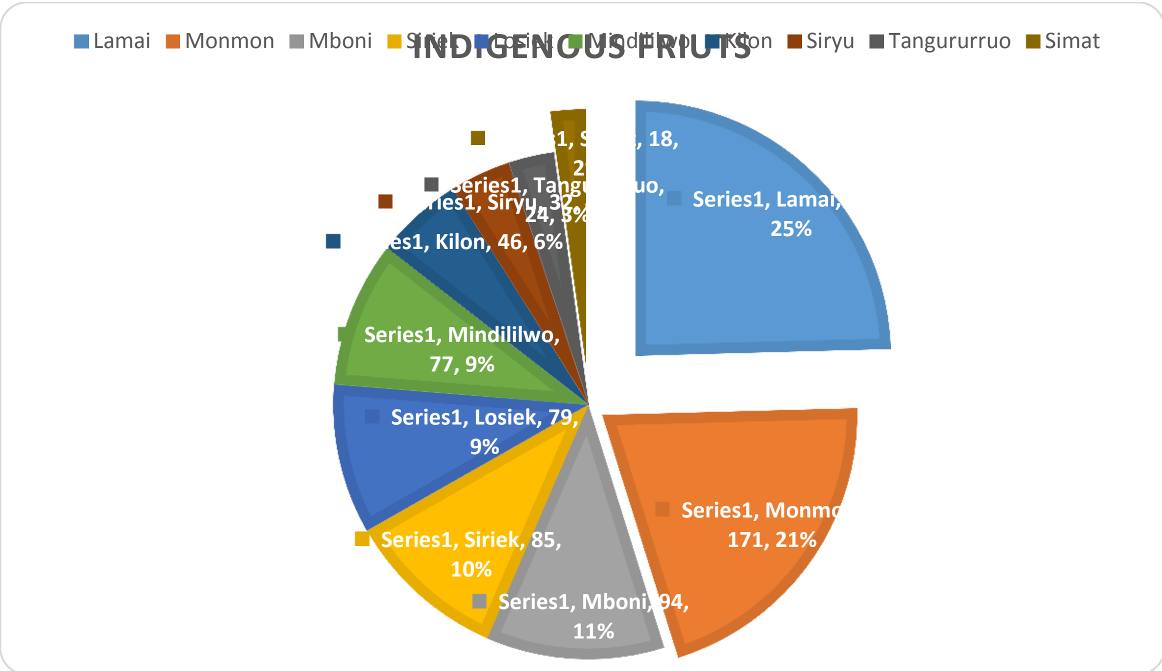

Figure 4. Ten most well-known indigenous fruits in Cherang'any

Vegetables

A total of 42 indigenous vegetables were identified by the respondents as being available in the forest. The nine most known by the respondents were; Kisoyo/Nderemia (African nightshade), Kimeley (Forest nettle), Saga (Spider plant), Dodo (Pigweed), Rachan (*Basella alba*), Chepkerta, Socho, Kiskiap-Ndok, and Sarat (Table 9, Figure 5). A vast majority (> 75 percent) were of the opinion that fruits were abundant (Table 9)

Table 9: Awareness and abundance of indigenous fruits in Cherang'any Hills Forest

Local name	Scientific name	English/common name	Proportion of respondents aware of the vegetable (in %, n = 266)	Proportion of respondents perceiving vegetable as abundant (in %)	Other Uses
Kisoyo/ Nderemia	*Solanum nigram*	African nightshade	65	84	Vitamins
Chepkerta			48	82	Vitamins
Kimeley	*Urtica massaica*	Forest nettle	35	99	Medicinal, local anesthesia
Socho			20	88	Quicken delivery
Saga	*Grandropsis gyanda*	Spider plant	16	91	
Kisakiap Ndok			11	93	Medicinal, Vitamins
Rachan	*Basella alba*		6	94	
Dodo	*Amaranthus spp*	Pigweed	6	81	Quicken delivery
Sarat			5	77	Vitamins

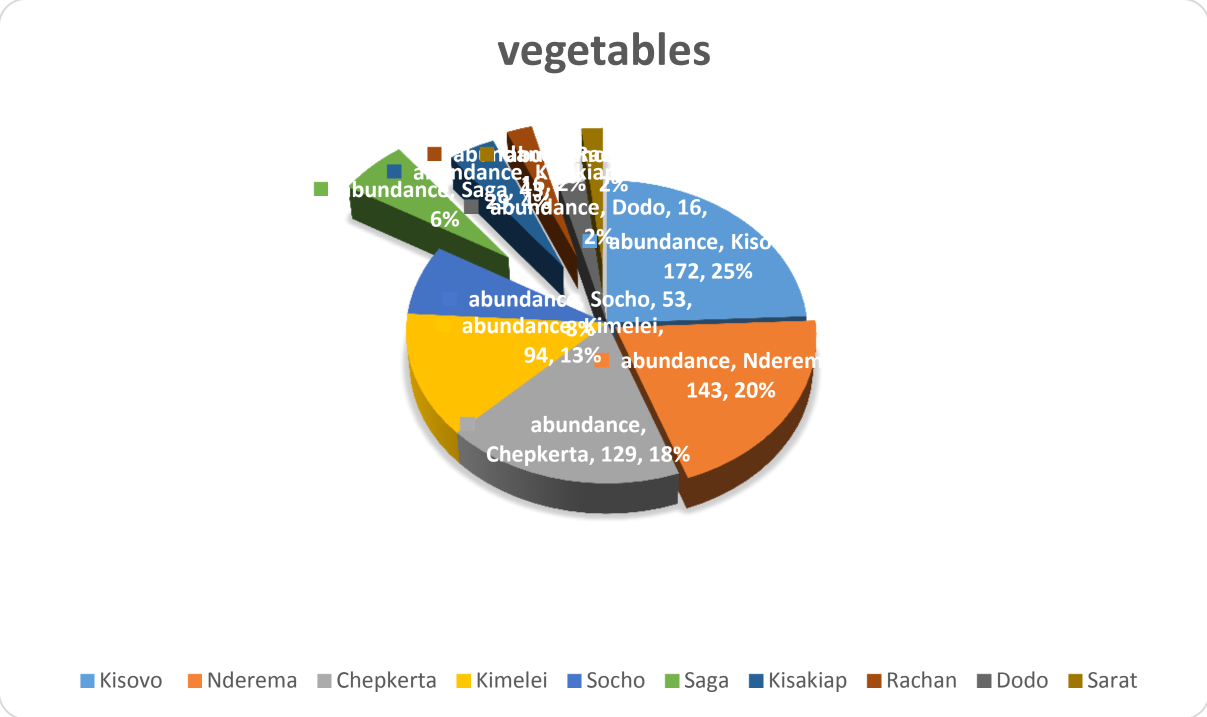

Figure 5. Awareness of various indigenous vegetables in Cherang'any

Conclusions

Most of the communities living around Cherang'any Hills Ecosystem are mainly full time peasant farmers with an average land size of 6 acre deriving 82 % of income from farming activities. The Ecosystem has a number of non-wood forest products (NWFPs) that include: honey, medicines, indigenous fruits, indigenous vegetables, grass (for fodder and thatching), bamboo shoots, gums, mushrooms, fibre, dyes, tannins, bush meat, aloe and tubers. However, the priority NWFPs are: Fodder, vegetables, medicine, ropes and honey. Fodder was the most sold product. The study also established that there was a diversity of indigenous fruits (40) and indigenous vegetables (42) though some of these are currently under-utilized and some are not abundant. Pockets of some exotic fruits (mango, avocado and passion) were found in the forest. There were also some pockets of passion and avocado fruits which were considered easily available by more than 50% of the respondents. All the above listed NWFPs were considered between moderately to easily available by at least 75% of the respondents. Only mushrooms, honey, bush-meat, roots and tubers and aloes were considered difficult to get by about 20% of the respondents.

The study revealed that the community members know that there are other benefits of the forest. The reason why the NWFPs are not exploited is because the communities lack the expertise and the knowledge that they can also get income from these products while conserving them.

Recommendations

- There is need to carry out taxonomical identification of plants that produce non-wood forest products in Cherang'any Hills documented during the survey in order to provide their scientific names for future reference
- It is also necessary to produce a checklist of the plant species that produce the non-wood forest products with information on where they are found in this ecosystem, approximate quantities, their description and uses.
- There is need to promote the conservation and sustainable utilization of indigenous fruits and vegetables in the Ecosystem.
- There is need to promote sustainable commercialization of fodder, vegetables, medicine, and honey
- There is need to provide training on the extraction, production and even value addition to some of these NWFPs so that the community can make a living out of these products.

Acknowledgements

The authors acknowledge with appreciation the financial support from the European Union Commission for facilitating this study through the WaTER Programme. The role played by Timon Owino, Michael Juma, Maureen Kabasa, Grace Mijide, Swapprinah Imbosa, Edna Kangogo, Vincent Ogoni, Dorothy Cherotich and Iliano Lodepewho who coded and entered the data into SPSS software is highly recognized and appreciated. The logistical support from Ms. Purity Karuga, Humphrey Gaya, Yusuf Ouko and Kennedy Mutunga is greatly acknowledged. Finally, the authors are indebted to the following WaTer programme Personnel: Mr. Paul Ongugo, (the Principal Investigator), Dr. Joshua Cheboiwo (Deputy Director, SPandG), and the Director, KEFRI for technical advice and logistical support.

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Review of the Wood Industry in Kenya: Technology Development, Challenges and Opportunities

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Abstract

Forests worldwide have significant economic, environmental, social and cultural values. Kenya forest sector is vibrant, undergoing a number of remarkable changes. It is estimated that the forestry sector contributes approximately 3.6% of the country's Gross Domestic Product (GDP). The sector contributes in excess of Ksh 20 billion (about 180 Million Euro) annually worth of goods to the economy. Forestry sector in Kenya is fairly supported by relevant policies and programmes geared towards sustainable management and aligning the sector to the country's vision and aspirations for the future. The creation of the National Forestry Programme (NFP) has revitalised the coordination of the sector, with private forestry emerging as a source for employment and wealth creation. The sector is however faced by numerous challenges to include and not limited to: inadequate forest sector funding, which impacts on possibilities to implement strategic policies like NFP; inadequate capacity of the County Governments to implement devolved forestry functions like overseeing management and utilization of the forest resource on community and private land and weak organizational framework to adequately support on-farm tree growing. Although re-vitalizing, the wood industry is struggling with technological challenges with a considerable number of inefficient processing systems, gaps in technical as well as business management skills to run wood processing business. Variations in rain patterns presumably due to climate change poses major setbacks in the development of forestry and forest products particularly in Arid and Semi-arid Lands (ASAL).

Background

Forest sector continues to support livelihoods in Kenyan, providing forest-related goods and services. The Kenya Green Economy Strategy Implementation Plan 2015 (GoK, 2015) STATES THAT NATURAL RESOURCE-BASED SECTORS CONTRIBUTE ABOUT 42% OF THE COUNTRY'S GDP. It's most significant contributions are in energy for industrial processes and domestic use. Other major uses include timber for building and construction as well as environmental services such as regulation of water flows, local climate conditions and provision of carbon reservoirs and sinks (Githiomi *et al*., 2012). The forest cover in Kenya declined during the period 1990 – 2000 from 7.98 to about 2.3%, but has now taken an upward trend, due to improved afforestation activities and is projected to reach about 7.5% in 2018 (KFS, 2013).

Loss in forest cover is highly attributed to among others, conversion of forest land to other uses. This is necessitated by the country's growing human population both in the rural and urban settlements (KFS, 2013). Consequently, the supply of forest products among them biomass energy, timber and non-timber forest products is far below the current demand (MENR, 2005). In 2012 the demand for round wood, was 41.7 million m^3 with a corresponding supply of 31.4 million m^3, leaving a deficit of 10.3 million m^3. This situation is expected to continue with a deficit of 15 million m^3 projected by 2032 (MEW&NR, 2013).While most of the wood processed in particularly large industries is primarily from state forests, private farms and communal lands, mainly in the Arid and Semi-Arid Lands (ASALs) provide over 90% of the total wood supplies in these areas, most of it being used for fuel (MEW&NR, 2013).

The contribution of forests towards economic, environmental, social and cultural values in Kenya cannot be underrated (ADB, 2007; Gatsby Foundation, 2016). It is estimated that the forestry sector contributes well over 20 billion Kenya shillings annually worth of goods to the economy, which is approximately 3.6% of the country's gross domestic product (GDP) (KFS 2014). Forests and forest product support other major sectors of the economy including building and construction, energy, agriculture, livestock, wildlife, water, fisheries, tourism and trade, thus cumulatively contributing to between 33% and 39% of GDP (MEW&NR, 2013).

Timber processing, especially from plantation forests plays a major role in the country's development (Republic of Kenya, 2016). In Kenya, sawmilling provide employment to many people in forested rural areas(Muthike, 2016). During the 1999 - 2011 ban that locked out the wood industries from state forests, wood supplies to most wood based industries got reduced, culminating in closure of most of the timber industries, particularly those in the Small and Medium Enterprise (SME) category. As a result, socio-economic development was adversely affected due to reduced employment opportunities especially in areas where the local economies depended on the industry (Muthike *et al*., 2010). It also resulted in an acute shortage of timber products, prompting increase in wood and wood products imports from neighbouring countries. Consequently, cross-border timber trade, both legal and illegal sprung, making timber trade a major challenge in the region (Samuel *et al*., 2007).

Farm forestry sub-sector contributes substantially to the growth of Kenya's economy as it does in other countries (Pasiecznik, 2010). With natural forests being increasingly protected for the „global good" and forest plantations having to compete with agriculture for limited space in state and communal land, trees growing on farms continue to be an important supplement (World Agro forestry Centre, 2004). In Kenya for example, during the ban, in an effort to sustain their operations, a few wood processing industries turned to farms as supplemental source of logs. This however became uneconomical due to increased distances to the tree source, decreasing volumes, cost of collecting few logs from farm to farm and decreased log quality. Local sawyers, using small-scale movable sawing systems took up the operations on farms to provide the highly needed sawn timber (Holding *et al*., 2001; Holding-Anyonge & Roshetko, 2003). However, most of these sawing systems have been shown to be inefficient, thus contributing to deforestation (Muthike*et al*., 2010).

In the absence of such efforts, outside traditional forest zones like in farms and dry lands, wood from unprocessed trees provide relatively little income when sold for fuel, posts or unprocessed logs. In some areas, studies on the sawn timber value chain indicated that tree owners get as little as 10% of the sawn timber value when they sell the trees unprocessed (Muhumuza *et al*., 2007). Sawing logs on-site therefore remain a favourable option and increases value and revenues to the tree farmers, encouraging them to plant more (Muthike *et al*., 2010). This also promotes local economies by providing raw materials for local needs and employment for the local population, who serve as saw operators and others along the value chain (Samuel *et al*., 2007).

On the farm, three movable sawing systems; bench, chain and pit saws are used (Pasiecznik, 2010; Muthike *et al*., 2010). Bench saw machines are common in areas where wood is available in relatively large quantities and easily accessible. Pit saws were used in very remote areas, especially where trees grow in steep terrains limiting access by bench machines. Due to the introduction of chainsaws, pit saws have become almost irrelevant. Chainsaws, although not initially designed for sawing dimensioned timber, have been adopted because they generally require relatively lower initial investment than bench saws and are faster than pit saws. They have been used in areas that are not easily accessible by conventional saw milling or the movable bench saw equipment (Pasiecznik and Brewer, 2006; Marfo, 2010). Their efficiency is relatively low compared to the other movable alternatives (Muthike *et al*., 2013).

In Kenya and a number of other countries particularly in Africa, chainsaws have constantly replaced the other systems and have become the dominant sawing system, particularly on farms (Muthike *et. al*., 2008; Marfo, 2010). Over the years, chainsaw system has become widespread as means for producing timber in small volumes from isolated trees and trees in difficult terrain as well as deformed logs. The sawing practice has evolved as a major source of livelihood for small-scale operators, farmers and the rural communities (Pasiecznik, 2010). These sawing systems involve less invasive equipment than conventional saw milling. They involve manual labour instead of mechanised skidders, while small hand-held machines are used instead of large heavy duty fixed mills (Wit *et. al*., 2010).

Forest Policy in Kenya

The Sustainable Development Goals (SDG) call for significantly mobilisation of resources from all sources and at all levels to finance sustainable forest management (SFM), and provide adequate incentives to developing countries, to promote forest conservation (MENR, 2005). Kenya’s Vision 2030 provides the country’s overall sustainable development framework (GoK, 2007). The overall objective of the vision is to transform Kenya into a middle-income country, providing a high quality life to all citizens by the year 2030. It is therefore the key reference point for the country’s macro and micro-economic development planning. The vision calls for effective management of forests in view of the envisaged development in order to ensure sustainability and the attainment of Constitutional threshold of 10% forest cover.

At the international and regional level, Kenya has affirmed its commitment to SFM by signing several Multilateral Environmental Agreements (MEAs) and the East Africa Community (EAC) Treaty and associated Protocols, policies and strategies. In line with these, several policies targeting the attainment of 10% forest cover have been formulated. These include the The Forests Act, 2005, the Agriculture (Farm Forestry) Rules, 2009 and the draft National Energy Policy, 2014. While forestry supports agriculture, agriculture relies on land for food security and its expansion has negative impacts on forestry (MENR), 2016). The National Food and Nutrition Security Policy, 2011 therefore lays emphasis on strategies aimed at enabling local communities to effectively adapt to climate change and reduce impact on food and nutrition security. Realisation of the objectives of these strategies in view of limited land and therefore competition for land uses requires more focus to be placed on enhancing land productivity, raw material conservation and efficient processing and utilization of natural resources. The vision 2030 therefore further gives attention to efficient wood based industrial development.

Management of Forest Resources
There are numerous actors and stakeholders in forestry and forest industry sectors in Kenya. The Ministry of Environment and Natural Resources (MENR) is the parent Ministry providing policy guidance and oversight in governance of environment and natural resources. The establishment of the National Forest Programme has gone a long way in coordinating the various actors in the sector for efficient work (MENR, 2016). Various state bodies under the Ministry of Environment and Natural Resources play their respective roles based on their specific mandates. Kenya Forest Service (KFS) is a semi-autonomous corporate body with a mandate to enhance development, conservation and management of Kenya's forest resource base in all public forests. KFS has the management responsibility of state forest plantations as well as the protection of gazetted indigenous forests. Furthermore, KFS is responsible for assisting County Governments to develop and manage forest resources on community and private lands through advisory services. Other ministries have supplementary roles depending on their specific interests connected to forestry and/or natural resources.

County Governments are responsible for some of the functions of the forestry sector devolved from the National Government. Gazette Supplement No. 116 of 9th of August 2014 specifies forestry functions to the County Governments. The devolved functions include forest advisory and extension services, creation of an enabling environment for forest enterprise development and funding of Sustainable Forest Management (SFM) models, especially on community and county government lands. Others include forests and game reserves formerly managed by Local Authorities, excluding forests managed by KFS, Kenya Water Tower Agency (KWTA) and private forests.

Forestry Research and Development
Research plays an important role in the development, management, conservation and utilization of forests and forest products. Kenya Forestry Research Institute (KEFRI) is a cooperate institution, whose mandate is to conduct research in forestry and allied natural resources. KEFRI undertakes research in forestry in four thematic areas: Forest Productivity

and Improvement; Biodiversity and Environmental Management; Forest Products Development and Socio-economics, Policy and Governance. Each of these thematic area is headed by a deputy director. Regional programmes implement the different thematic mandates in their respective climatic regions of the country. The Forest Products Development thematic area cuts across all the other themes, spearheading forest products development, utilization and marketing. This is implemented through the National Forest Products Research Programme (NFPRP).This programme has the mandate to develop technologies for processing and utilization of timber and non-timber forest products. The information and technologies generated through research is disseminated to the public in appropriate packages including but not limited to production and processing guidelines, policy briefs and guidelines, technology operation guidelines, research notes as well as conference and peer reviewed journal publications. KFS, forest industries and tree farmers are major consumers of these information packages. KEFRI also offers consultancy and advisory services to the forestry sector and the industry.

Forest Systems in Kenya

General Overview

The bulk of forests in Kenya are natural forests. Most of the natural forests (about 3.3 million ha) are owned and/or managed by communities, most of them being woodland-type forests in the Arid and Semi-Arid Lands (ASaLs) (IUCN, 2001). Natural forests in higher rainfall areas are typically public gazetted forests, managed by KFS. The natural forests are important for hosts for wildlife, as water catchment and regulators and as source of wood energy. Over 80% of Kenya's energy requirements come from wood and the main source is the ASAL woodlands (Githiomi *et al*., 2012). Available statistics indicate that a total of about 232,300 hectares of forest plantations are established the country. There is some substantial area under farm grown trees.

Plantation Forestry

The major part of the forest area (about 60%) in Kenya is state plantations managed by KFS. These form a total of 149,922 ha located mainly in Rift Valley and Central regions of Kenya. The rest are mainly small scale industrial plantations owned by tea companies and wood lots privately owned by individual farmers. However, there is no reliable information available on the total extent of forests owned by individuals due to lack of structured data base (KFS, 2012).

At the moment, establishment of forest plantations is mainly carried out by communities neighbouring forest stations. This is done through Plantation Establishment through Livelihood Improvement Systems (PELIS), which is a contractual arrangement between Community Forest Associations (CFAs) and KFS. In addition, in some areas, the wood industry players participate through voluntary monetary and labour contributions towards seedling production and planting. Silvicultural treatment (pruning and thinning) is carried out by KFS labour and to some extent by CFAs. Wood from thinning and clear felling is sold on stumpage to the wood industry, based on short-term allocations to prequalified industry operators. Wood harvesting from plantations is guided by the national allowable cut computations, which is updated annually through the forest management and felling plans. Timber harvesting has however steadily increased since the lifting of the logging ban and is currently around 1.5 million m^3 (KFS, 2013).

Challenges

The period of the ban (1999 – 2011), posed more than a decade of minimal management inputs into forests and low harvesting. As a result, the quality and stocking levels of stands were affected. Currently, plantation forests are not optimally distributed due to a large gap between over mature and very young plantations. In addition, there have been inadequate silvicultural operations leading to prevalence of pests, diseases and rot in wood. With a steady increase in demand for round wood from the expanding industry, there is already a general decline in supply of mature round wood for specialised uses like plywood making. This is likely to increase and affect other uses like sawn timber due to the skewed tree population distribution (IUCN, 2001).

Considering forest productivity and quality, the recently introduced PELIS may pose some risks in plantation establishment through intercropping. The farmers could give more attention to the agricultural crops than the trees being established. This could result in poor establishment and growth in some young plantations and hence low quality wood for industrial use at maturity. To mitigate these risks, the system needs high level of supervision, specifications on the type of crops to be intercropped with tree seedlings and close monitoring. Lack of adequate resources and inadequate modalities for monitoring as well as weak CFAs have already been reported as contributing to the poor performance of PELIS in some areas. In other areas, management of post-PELIS stands is inadequate, with low levels of pruning, thinning and use of out-dated methods and equipment.

Opportunities

There are opportunities for improvement in productivity and sustainable economic returns from forestry. PELIS system can help in fast establishment of forest plantations. If well managed, it can provide low cost care for seedlings to healthy stands, while providing livelihoods for the farmers. The system can be scaled up and enhanced through community involvement in silvicultural activities beyond PELIS. This will however require strengthening capacities of the responsible institutions. The CFAs need to be engaged more in training their members and developing capacities among the people engaged as well as taking the CFA involvement into consideration when developing management methods. There is also need to further refine roles and responsibilities between KFS and other public and private sector partners, emphasising their respective roles and synergy in forest development and management. There are potential gains in developing wood harvesting and processing methods that capture the true value and lead to optimum economic utilization of the available wood. Investment in efficient wood harvesting and processing technologies is a necessary consideration during this period of growing shortage and demand for industrial round wood.

Farm Forestry

There is little information available on the current extent of farm forestry in Kenya. However, tree growing on farms has been on-going all over Kenya. A major driver for tree growing on farms is income from sales of trees. Like in many other countries, farmers in Kenya look at their plantations as a "bank" to be utilized when income is needed (Muthike, 2016; Pasiezcnik, 2010). *Eucalyptus* and *Grevillea* species are by far the most common tree species grown on farms in Kenya. The underlying factors for preference of these species include the current growing demand for *Eucalyptus* power transmission poles and shorter rotation period of 7 – 12 years for a variety of end products compared to over 20 years for *Pinus* and *Cupressus* species.

Tree growing on farms take different patterns depending on the available land. Farmers with less than 2 ha of farm land tend to grow trees along the borders while those with more land establish wood lots and plantations. Intercropping trees with crops during the first 3 years is typical in many areas in Kenya. A study by World Bank in 1980's, gave an indication that there is potential in farms to supplement state forest land for tree growing. More work by Githiomi *et al*, (2012) indicated that more fuel wood was being sourced from farms that state forest plantations. This shows that tree growing on farms has gained importance, with support being acquired from various local and international organizations. There also exist numerous associations and groups of tree growers at community level, many of them under the Farm Forestry Smallholder Producers Association of Kenya (FF-SPAK) which is an umbrella organisation for local tree growers‟ associations. So far FF-SPAK has been carrying out capacity building interventions to its members. There is also the Kenya Forest Growers Association (KEFGA), established in 2008 and has about 300 members with trees ranging from small scale wood lots to large-scale forests of more than 200 ha.

In addition, various actors and support groups have found space in Kenya's farm forestry. The German Ministry of Agriculture is at the moment starting up support to some tree growers in Kericho and Nakuru counties. Gatsby Foundation is at its initial phase of its "Kenya Commercial Forestry Programme" in June 2016 which focuses on improving tree seeds, plantation establishment and marketing of wood products. The programme is working with both small-scale farmers and industrial plantations through Kenya Tea Development Agency (KTDA). KOMAZA, a social enterprise established in 2006 is also supporting tree growing and marketing in the dry and coastal areas of the country. At the moment the company has engaged with about 6000 farmers that have so far established around 2000 ha of small scale woodlots of Eucalyptus and/or *Melia volkensiii* species (KOMAZA, 2016). Trees grown under support and advice from the enterprise are owned by the enterprise with farmers providing inputs in form of land and labour and receiving income when the trees are sold. The company is planning to establish its own wood processing facilities in future.

Challenges

Farm forestry in Kenya is generally hampered by low quality germplasm as well as weaknesses in establishment and management of trees for industrial use. This is mainly due to inadequate capacity and knowledge among farmers, who are more conversant with crops than trees (Pascieznik *et al*., 2006). Private tree growers in Kenya are typically passive players in forestry and wood market. They rarely would seek advice from foresters on the way to grow trees for a particular end product, thus at maturity, most of the trees lack placement in the market. Many farmers with trees wait to be approached by interested traders and lack skills in valuation of the trees as well as marketing. For example, some years back Eucalyptus growing was triggered by a high demand for power transmission poles. Due to abundant planting, imports and introduction of concrete poles, there is currently an over-supply of poles. As a result, tree growers have challenges in selling their *Eucalyptus* as transmission poles and prices have fallen sharply, prompting search for alternative uses, which many farmers are unable to do.

The sawn timber and wood panel industry predominantly source their wood from state plantations. Due to supply from private farms being small volumes, lower quality and with logistical challenges, there is generally no interest in sourcing from private farms. Instead private tree growers have to engage with small processors like chainsaw and mobile bench operators to process their trees. This results in lower recovery and low quality of the sawn timber (Muthike *et al*., 2013). Many of the tree farmers lack skills and capacity to recognize inefficient processing and poor quality end product when they have their trees processed by the operators. Similarly, many of the small-scale processing operators do not put emphasis on efficient processing since they are paid based on quantity and not quality of the timber from the trees they process.

Opportunities

Demand for wood products (fuel wood, sawn timber, wood panels, pulp & paper) is ever growing in Kenya. Through proper tree management and efficient processing efforts, this can be translated to income for private tree farmers. Furthermore, there are indications that supply of wood from state plantations may not adequately satisfy the growing demand in the near future. Through proper interventions, private tree growers can be well positioned to address supply shortages and increase their earnings from the farms.

The Forest Industry and Utilization of Forest Resource

The largest volume of round wood from plantations in Kenya goes to sawn timber and wood composites. Until the year 2011, the wood composite sector was dominated by a few big producers. Lately, Small and Medium Enterprise (SMEs) producers investing in processing equipment have emerged. One of the main driving forces behind the investments is the increased cost of round wood from state plantations, hence the need for higher recovery of the available raw material into higher value. With the only round wood using pulp and paper mill closed since 2009, now been revived, its demand for raw materials will impact on supply to the growing number of SME wood processors.

The sawmilling industry is now re-vitalizing and moving towards more efficient processing. Many are investing in horizontal band saws, moving away from the earlier circular saws. According to KFS re-classification in May 2016 there are about 29 sawmills classified as large with sawn timber production of over 20 m^3/day and 175 sawmills classified as medium scale with sawn timber production 10 – 20 m^3/per day. All these saw mills rely on state plantations for their round wood supply. Very little is sourced from private plantations, mainly due to volumes, quality and logistical challenges.

Some wood is used as industrial and domestic fuel wood by especially tea factories and households in rural areas respectively. Although most of the tea factories rely heavily on wood from farms while others grow their own wood lots and small plantations, substantial supplies come from the forest plantations, especially the *Eucalyptus* species.

Challenges

Although the sawmilling industry is undergoing re-vitalization, there is still a big number of sawmills using old and in-efficient technology. The bulk of existing sawmills (473 of the 677 classified sawmills by KFS) is still small units with sawn timber production of less than 5 m^3 per day. To optimize on efficiency in resource utilization, there is a need for revitalization of the sub-sector. Investment in new technology seem to have led to a gap in capacity and technical skills to run the sawmills. There are also indications of weaknesses in business and management skills.

At the moment, majority of sawn timber is produced without seasoning and/or grading. This results in low quality products downstream as well as inefficient application of sawn timber in construction industry due to over-dimensioning to compensate for inferior quality. Post sawing handling of timber needs to be in cooperated in the industry. Before the ban, timber grading courses were conducted by the sector players (KEFRI, KFS, MOPW, KBS and timber industry). Revival of this course could go a long way in offering a solution to the challenges of over designing of timber structures. There is need to promote integrated timber processing in particularly the SME sector for higher value addition.

Opportunities

The ever increasing demand for wood products presents good opportunities for enterprise development and employment creation by strengthening the SME wood industry. This can be done through awareness and promotion activities as well as entrepreneurship facilitation. Vocational training will play important role in developing technical work force in the sector. Proper engagement of farm forestry as suppliers of wood can mitigate the impacts of shortage in wood supply from state plantations. Dry areas can be matched with appropriate tree species to provide additional supply of round wood in the future. There are indications that there is a growing awareness and preparedness to pay more for better quality sawn timber. This can be built upon and further promoted through among others value addition procedures like timber seasoning and grading and secondary processing.

The on-going re-vitalization of the industry provides for good opportunities for training. Vocational training may become a very important part of the operations in the sector. During the logging ban, KTMA lost momentum and also importance among its members. Now, when industry is growing and modernizing, there is definitely room for an industry professional association to be in the centre for lobbying, coordination and awareness creation. Curricular needs to be developed geared towards answering some of the skill-based challenges that the industry is facing at the moment.

The Way Forward

Sound management of forests involving private sector can lead to improved forest productivity, increased employment and improved livelihoods. A more efficient management may be achieved through Private-Public Partnership arrangements with private sector, taking a more emphasized role in short term management of plantations. Improved forest products and marketing can also be achieved on farms through better competencies among farmers and processors, resulting in improved quality of round wood and value added products coming out from farms.

Revitalization of sawmilling industry has continued with increasing number of wood industries coming into the sector using different processing systems. Research should be continued to develop data on wood intake capacities and timber recovery rates for various categories of wood industries in the sector. This would assist the Government in optimizing the allocation of the available wood materials based on need for the industry. In addition, Kenya Forestry Research Institute (KEFRI) and other stakeholders need to provide information on the currently used logging practices and develop technologies for enhancing wood recovery during logging.

Acknowledgements

This study was facilitated by Kenya Forestry Research Institute through the Government of Kenya Research Funds. The authors wish therefore to appreciate the support and timely delivery of necessary resources by the Director KEFRI.

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Synthesis of the Development in Gums and Resins Sub-Sector in Kenya

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Abstract

Gums and resins of commercial value in Kenya include: gum arabic; myrrh; hagar; and frankincense. This paper synthesizes what has been done and achievements made in the sub-sector since 1988 as well as future prospects. The aim is to inform private and public institutions interested in the gums and resins and policy makers. The key achievements in this sub-sector include: taxonomic, ecological and chemical characterization of gums and resins, characterization of soil physico-chemical properties, establishment of genetic diversity and population structure of *Acacia senegal*, piloting of plantation development of *A. senegal*, resource assessment and mapping, market chain analysis, capacity building of stakeholders and feasibility studies on the potential for commercialization of the processing of the products. The potential annual production for gum arabic is about 16,291 metric tonnes while that for resins is about 10,134.5 metric tonnes with main markets in Europe (gum Arabic) and Asia (gum resins). Kenya's exports are about 59 metric tonnes for gum arabic and 2446 metric tonnes for resins. Challenges of low export volumes are partly due to incapacity to bulk enough quantities mainly collected from the wild and lack of reliable suppliers. The government has now prepared the gums and resins regulations currently awaiting gazettement. The current interests from foreign investors are expected to streamline the sub-sector and make the trade in gums and resins sustainable, more structured, more profitable and beneficial to the resource poor pastoral collectors. From the synthesis, it is concluded that the developments made in the sub-sector have not translated into volumes marketed. More efforts therefore are necessary to stimulate and enhance volumes collected and marketed.

Keywords: frankincense, gum arabic, hagar, myrrh, production, resins, marketing

Introduction

Plant gums and resins include gum arabic from *Acacia senegal* (L.) Willd. or *Acacia seyal* Del. and commercial gum resins such as Myrrh from *Commiphora myrrha* (Nees) Engl., Hagar from *Commiphora holtziana* Engl. and Frankincense from *Boswellia neglecta* S. Moore. Currently, gums and resins are produced in at least seven ASAL Counties in Kenya namely: Marsabit, Wajir, Garissa, Mandera, Turkana, Samburu and Isiolo (Muga *et al.*, 2017). Investment in gums and resins has dual potential of environmental conservation and generation of wealth to uplift the living standards of the local communities in the dry lands.

They serve as raw materials for enterprise development thus providing opportunities for trade and employment generation.

Two major regional projects, namely Acacia Operation and Acacia Gum with Kenya as one of the beneficiary countries were implemented between 2004 and 2011 to improve the gums and resins subsector and build capacity of producing communities. Key achievements from the two projects and other initiatives in the sub-sector include: Taxonomic, ecological and chemical characterization of gums and resins (Gachathi, 1994, Gachathi and Muga, 2009, Chikamai, and Hall, 1995, Chikamai, 2001, Chiteva, 2013); review and synthesis on the state of knowledge of Boswellia species and commercialisation of frankincense (Chikamai, and Kagombe. 2002); characterization of soil physico-chemical properties of different varieties of *A. senegal* (Lelon *et al*., 2010); preliminary resource assessment and mapping of gums and resins producing species in Kenya (FAO, 2005, Chikamai *et al*., 1995); piloting of production and management of *Acacia senegal* trees (Keya *et al*., 2008, Muga, 2013); traditional ecological knowledge associated with *Acacia senegal* management and gum arabic production (Wekesa *et al*., 2010); capacity building of extension agents and communities in some of the producing counties in production, processing and marketing of gums and resins (Chikamai *et al*., 2010, Muga *et al*., 2010) and studies on genetic diversity in Kenyan populations of *Acacia senegal* (L) Wild (Chiveu, 2008,Omondi, *et al.*, 2010, Omondi *et al*.,2016, Omondi *et al*., 2018). Resource assessment and mapping have also been carried out in major production counties (Muga *et al*., 2012, Muga *et al*., 2014, Luvanda *et al*, 2014, Muga *et al*., 2016, Luvanda *et al*, 2016 and Muga *et al*., 2017). The traditional ecological knowledge and its application in the management of *Acacia senegal* trees in Isiolo and Samburu counties has been documented Wekesa *et al*., 2010. The market chains of gum arabic, the stakeholders participating in the management and marketing of *Acacia senegal* products and the constraints to gum arabic production and collection within the Kenyan drylands have also been documented (Wekesa *et al*., 2010). Gum arabic yield in different varieties of *Acacia senegal* has also been studied (Wekesa *et al*., 2015). Draft protocols for sustainable wild harvesting of *Acacia senegal* var. kerensis and *Commiphora holtziana* have also been developed (Muga *et al*., 2017). A review of the policy environment for gums and resins has also been carried out (Luvanda and Muga, 2013). Similarly, through these past initiatives, major barriers that limit the realization of full potential for the gums and resins in the dry lands of Kenya have been identified and classified as ecological and climatic issues, socio-economic factors, technological barriers and policy as well as institutional barriers (Gachathi *et al*., 2010; Muga *et al.*, 2017). The government has also prepared the gums and resins regulations that are waiting gazetting by the Cabinet Secretary for Environment and Forestry. This paper summarizes the data on primary production, harvesting and post-harvest handling, value added processing, trade and marketing of gums and resins, research and development within the sub-sector, policy environment, challenges and opportunities.

Primary Production of Gums and Resins in Kenya

Gums and resins are produced mainly in seven ASAL Counties, namely: Marsabit, Wajir, Garissa, Mandera, Turkana, Samburu and Isiolo though there are other counties with the resources such as Kitui, Mwingi and Meru. The areas with high probability of the presence of these resources in the country is illustrated in Figure 1. Based on resource assessment studies, the potential annual production for gum arabic (from *Acacia senegal* only) is about 16,291 MT against 1,510 MT while that for resins (myrrh and opoponax) is about 10,135 MT against 3631 MT (Table 1) Luvanda *et al*., 2014, Muga *et al*., 2016 and Muga *et al.*,2017.

Table 1. Potential Production of gums and resins in Kenya

County	Gum arabic	Myrr	Frankincense	Hagar (Opoponax)
Isiolo	6,818.8	-	-	3,752.2
Samburu	4,771.9	-	-	-
Turkana	4,700	-	-	-
Wajir	-	644.8	1,800	1,978.5
Mandera				
Garissa	-	-	-	1,959
Total	**16,290.7**	**644.8**	**1,800**	**7,689.7**

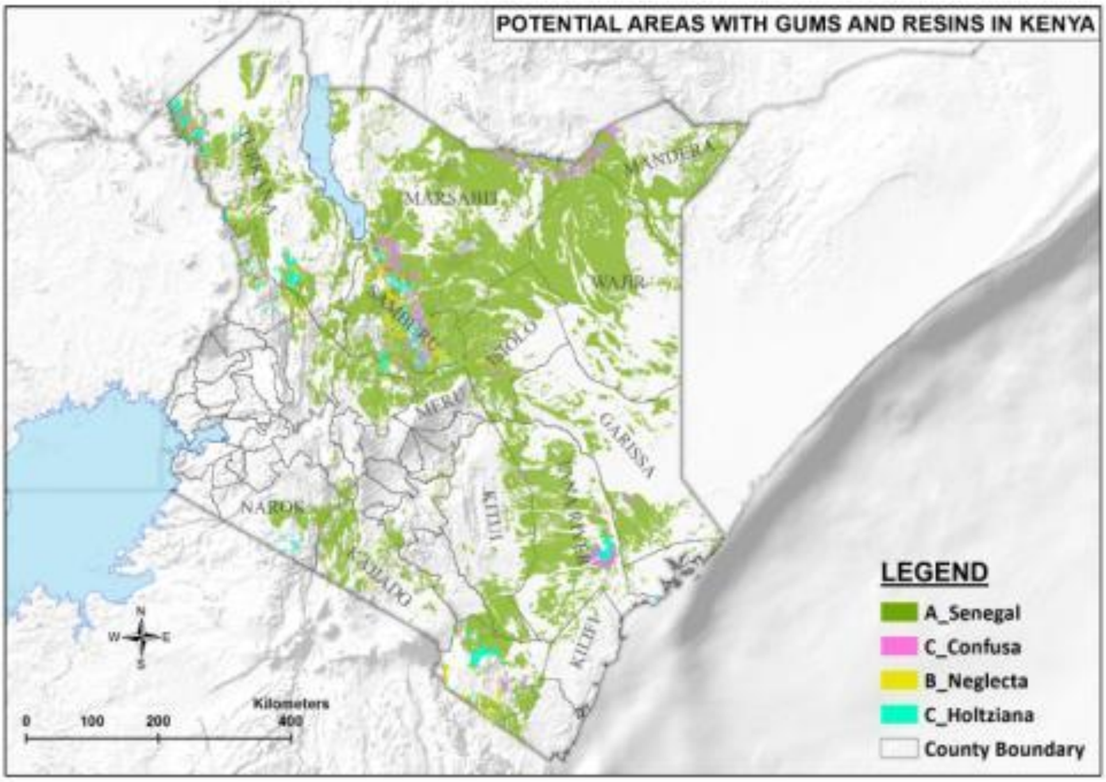

Figure 1. Probability map for gums and resins resources in Kenya (Muga *et al*., 2017)

Harvesting and Post Harvest Handling

Harvesting of Gum arabic

Harvesting of gum arabic in Kenya is done by natural exudation though studies have shown that tapping can increase yield by between 42% and 110% (Wekesa *et al*., 2015). The main gum collection season in Kenya is December-March and June-September (Muga *et al.*, 2017). An average of 4 to 7 Kg/day of gum arabic is collected per person per day (Gachathi *et al.*, 2010).

Harvesting of Gum resins

Hagar and frankincense are harvested from the wild from exudations caused by insects, animal damage or natural exudation while myrrh is mainly tapped. Tapping is done using a special axe in the dry seasons (three weeks after the rains) mainly in May – October and occasionally in January-March (Muga and Chikamai, 2016). A small area of back about 3 cm wide and 10 cm long is removed from the tree stem starting from the base and first collection made after 21 days (Muga and Chikamai, 2016). An average of 5-6 kg of gum/resins is collected per person per day (Gachathi *et al.,* 2010).

Value Added Processing

A study by Muga and Chikamai (2016) has reported that most of the gums and resins produced in Kenya are exported in raw form except for a small quantity of the total volume produced that is processed for essential oils. There are three processors of gum resins in Kenya namely: Lubanchem Limited, Northern Gums Limited and Arbor Oils of Africa Ltd, which extract essential oils from myrrh, Olibanum (Frankincense) and Opoponax (Hagar) through steam distillation process. Lubanchem Limited has an efficiency level of 70%, resulting in a yield of essential oils of 5% for myrrh and 6% for Olibanum and Hagar. A gum resins processing plant has also been constructed in Wajir through the support of the Economic Stimulus Programme under the Vision 2030 for value addition, but is yet to be operationalized (Muga *et al.*, 2015; Muga *et al.*, 2017). For gum arabic, it is only Arid Land Resources Limited (ALRL) that carries out value addition to gum arabic by grinding the product and grading it before exporting (Muga and Chikamai, 2016).

Trade and Marketing of Gums and Resins

Gums and resins are marketed through the local, national and export marketing outlets. The collectors who are mostly cattle herders and women members of the communities within producing sites sell their collections averaging 10 Kg/person to local dealers who mostly operate grocery or hides and skins business shops at local market centres. The volumes bulked are then sold off to national dealers. The merchandise is then sold to manufacturers or exported.

The current annual world demand for gum arabic is about 100,000 MT against a current supply of about 70,000 MT which is projected to reach 150,000 MT by 2020 (Muller and Okoro, 2004). Annual exports of gum arabic have been only a paltry 58.8 MT which reached a peak of 165 MT in 2008 valued at US $ 151,715.8. The exports are mainly to Germany. However, there is a huge internal market that takes about 100 MT annually. The annual world demand for gum resins is estimated at around 2,500 MT. The low export volumes are partly due to capacity to bulk enough quantities and lack of reliable suppliers. The gums are collected from the wild mostly by cattle herders compromising volumes and reliability of supplies.

Kenya is the third largest exporter of resins (myrrh, hagar and frankincense) after Ethiopia and Somalia. Export volumes of gum resins averaged 2,445.8 MT per annum (2005-2015) and reached a peak of 3,687 MT in 2012 valued at US$ 4,010,726.3 and sold mainly to Pakistan, Vietnam, China, Hong Kong and India (Kenya National Bureau of Statistics, Table 2). The key challenge with marketing of resins just like gum arabic is unreliability in supplies and low bulking capacities by dealers.

Research and Development Within the Sub-Sector

A number of research and development initiatives have been undertaken since the 1990s through various projects. Some of the key areas of focus have been: Taxonomic and ecological characterization of the producing species, chemical characterization of the gums and resins, resource assessment and mapping, piloting production and management of *Acacia senegal* trees and training and capacity building. Each of these is briefly described below.

Taxonomic and Ecological Characterization of gums and resins species

The key gum arabic producing species in Kenya, *Acacia senegal* and *Acacia seyal* have been characterized in terms of their taxonomy and ecology (Gachathi, 1994 and Chikamai, 2001, Gachathi and Muga, 2009). The potential adulterants have also been identified (Gachathi and Muga, 2009). *Acacia senegal* has three varieties namely: *Acacia senegal* var. *senegal* (Figure 2), *Acacia senegal* var. *kerensis* (Figure 3), and *Acacia senegal var*. *leiorhachis* (Figure 4). *Acacia senegal* var. *kerensis*, is the main source of commercial gum arabic in Kenya. *Variety senegal* occurs in areas of relatively higher rainfall, produces gum on tapping in some areas but not been developed commercially. Variety *leiorhachis* is more restricted but its potential for gum production has not been established. Other sources of gum arabic are Acacia seyal var. seyal (Figure 5) and *Acacia seyal* var. *fistula* (Figure 6).

Figure 2. Acacia senegal var. *senegal*
(Source: Gachathi and Muga, 2009)

Figure 3. Acacia senegal *var. kerensis*

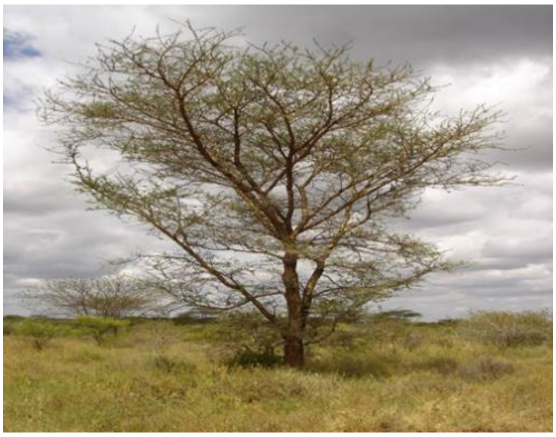

Figure 4. Acacia senegal var. *leiorhachis*

Figure 5. Acacia seyal var. *seyal*

Figure 6. Acacia seyal var. fistula

(Source: Gachathi and Muga, 2008**)**

Gum resins producing species

Commiphora myrrha is the source of myrrh, the main *Commiphora* gum resin of economic importance locally known as Malmal in Somali. Other local names include Khumbi (Boran); Malmal, Molmol (Somali, the gum); Didin (Somali, the tree).

Figure 7. *Commiphora myrrha* tree

Figure 8. *Commiphora myrrha* stem

Figure 9. Myr*rh*

Figure 10. *Commiphora myrrha* leaves

Commiphora holtziana (*C. erythraea*) (Figure 11) is the source of the gum resin known as Hagar, used locally to control ticks. Local names include: Haggersu (Borana); Agarsu (Gabra); Haggr-ad (Somali). Figures 12 and 13 show the bark on the stem and leaves respectively

Figure 11. *Commiphora holtziana tree*

Figure 12. *Commiphora holtziana* Stem/Bark

Figure 13. *Commiphora holtziana* leaves

Boswellia neglecta (*B. hildebrandtii*) is the source of frankincense the main *Boswellia* gum resin of economic importance in Kenya. Local names include: Dakhara, Hancha (Borana, Gabra), Kinodo (Kamba), Dakar (Orma), Lecholoo, Lkinoo (Samburu), Mathefur, Magafur (Somali). (Figure 14, 15 and 16 showing a tree in the wild, a fruiting branch and frankincense respectively)

Figure 14. *Boswellia neglecta* tree

Figure 15. *Boswellia neglecta* fruiting branch

Figure 16. Frankincense

Chemical Characterization

Gum arabic

The chemical characteristics of the three varieties of *Acacia senegal* have been studied by Anderson *et al.* (1990), Chikamai and Banks (1993), and Mhinzi and Mrosso (1997). The studies indicate that variety *kerensis* has a similar protein and nitrogen content (2.9 % and 0.44 %) to variety *leiorhachis* and higher values than variety *senegal* (2.3 % and 0.34 %, respectively) and also a higher intrinsic viscosity (21.9 ml/g) than variety *senegal* (16.0 ml/g) but lower values than variety *leiorhachis* (23 ml/g).

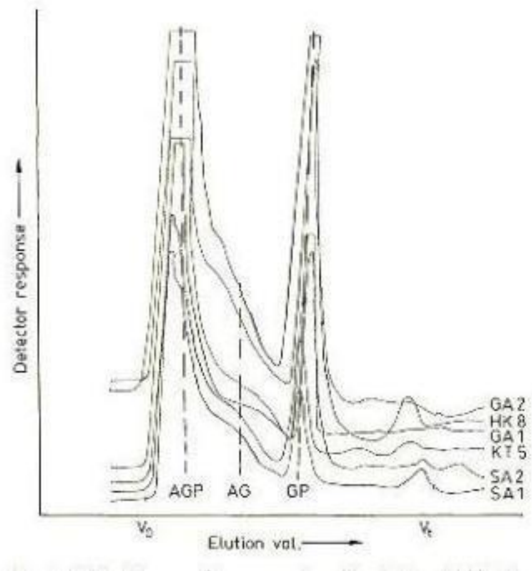

Figure 17. GPC elution profiles as monitored by UV
(Source: Chikamai *et al*., 1994)

When the molecular characteristics are examined the two varieties i.e. var *senegal* and *kerensis* show the same chemical characteristics typical of *Acacia senegal* though var. *kerensis* shows a more enhanced absorbance peaks of the UV profile caused by the high protein content (Figure 17). These differences reflect the natural variability that exists in the different varieties and presents opportunities for the development of specific niche markets for each type of gum.

***Commiphora holtziana* gum resins (Opoponax/ Hagar)**

Commiphora holtziana gum resin when solvent extracted followed by a combination of chromatographic separation techniques on hexane extract of a sample from Wajir, led to the isolation and characterization of a new compound, 11–hydroxy-γ-muurolene 1 (Chiteva *et al*. 2013). In addition, two known compounds, (1E)-2-methoxy-8,12 epoxygermacra-1(10),7,11-triene-6-one 2 and (1E)-3-methoxy-8,12-epoxygermacra-1,7(8),10(15),11-tetraen-6one 3 were also characterized. A total of 14 compounds were identified by the comparison of the mass spectra with data available in the GC – MS library. Both dichloromethane and hexane extracts from both Isiolo and Wajir populations showed antibacterial activity. In addition, the hexane extract from Wajir population showed antifungal properties. The acetone extract from Wajir population showed antibacterial properties. Activities were observed against Fungi, Gram (+) bacteria and Gram (-) bacteria. Pure compounds did not show any activity.

Piloting plantation production and management of Acacia gums

Plantation production of *Acacia senegal var.kerensis* has been piloted through the support of the Acacia Operation Project, a regional project, funded by the Italian Cooperation through Food and Agriculture Organisation (FAO) and implemented in 2004-2007. Through the application of a mechanized water harvesting Technology (Vallerani System), pilot sites were established in Marsabit and Samburu counties. A total of 2,485 trees survived in one of the most promising pilot sites (18.6 ha in size) at Laisamis. An assessment of the *Acacia senegal* trees at about 4 years indicated a mean height of 59.4 cm (ranging from 30 to 235 cm) and a mean diameter at ground level of 10.6 mm (ranging from 5 to 32 mm). However, there were challenges of protection of the pilot sites from domestic and wild animals resulting in the destruction of a number of trees.

Genetic diversity and population structure of gums and resins producing species

Studies on the genetic diversity of the Kenyan populations of *Acacia senegal* using nuclear and mitochondrial microsatellite markers have also been carried out and higher genetic diversity and little population structuring detected (Omondi *et al*., 2010). Similarly, morphological characterization of the Kenyan populations of *Acacia senegal* has also been completed and data analysis underway. Characterization of the populations using randomly amplified polymorphic DNA (RAPD) has also been accomplished showing high genetic diversity (Chiveu *et al*., 2008). Mating systems and effect of anthropogenic disturbance on genetic diversity show that the species is predominantly outcrossing and is vulnerable genetically to human disturbances (Omondi *et al*., 2016, 2018)

Effect of soil chemical characteristics on gum quality

The effect of chemical properties of soils on gum Arabic elementary compositions from *Acacia senegal* variety *kerensis* in Samburu and Marsabit Counties has been studied (Lelon *et al*., 2010). Chemical properties of soils were found to be major factors that influenced the gum arabic quality. The studies indicate that soil pH varied significantly ($p < 0.05$) with pH of gum in all the sites. Organic carbon in gum arabic from Merille (0.15%) was significantly higher than those in Logologo (0.073 %), Laisamis (0.055%) and Sereolipi (0.027 %). Soil nitrogen content in Merrile (0.30 %), Laisamis (0.4 %) and Logologo (0.8 %) were significantly correlated ($p < 0.05$) to the nitrogen (0.31 - 0.32%) in gum Phosphorus in gum arabic from Sereolipi (700.2 ppm) and Merrile (705.2 ppm) were significantly higher than in Laisamis (412.2 ppm) and Logologo (412. 2 ppm). The pH (4.5 - 4.54) and nitrogen content (0.31 - 0.32%) in gum arabic from Merrile, Laisamis and Logologo are within the international standards (pH 4.2 - 4.8) and (0.24 - 0.41%).

Training and capacity building

Since 2005, KEFRI in the framework of the Network for Natural Gums and Resins in Africa (NGARA) and in collaboration with Gums and Resins Association (GARA) has spearheaded the formation of at least 80 gum producer associations. In collabaration with Ewaso Ngiro North Development Authority (ENNDA), Acts-CRM Facility and National Agriculture and Livestock Extension Programme (NALEP) 387 people have been trained on the production, harvesting, post-harvest handling and marketing of gum arabic with the ultimate objective of providing an alternative livelihood source (income generation) for the local community.

Policy Environment

A review of the existing policy and legislative environment affecting the production, utilization and marketing of gums and resins resources in Kenya was done to examine the extent to which the existing policies and legislation framework address concerns of stakeholders in the sub-sector (Luvanda and Muga, 2013). A number of challenges and opportunities with respect to the policies and legislations in the sub-sector have been identified. The review established that Kenya has no legal and policy framework that that explicitly deals with gums and resins. The existing policies and legal frameworks, have certain provisions that are relevant to promotion of production and marketing of gums and resins, but do not effectively address several aspects of the problem. It is established that the existing laws and policies require harmonization, coordination and re-alignment to Vision 2030 and the constitution of Kenya in order to be clear on the gums and resins sub-sector. The government has therefore prepared the gums and resins regulations that are waiting gazettement to help regulate the sector.

Challenges and Opportunities

The key challenges for the sub-sector are:

- Poorly developed markets and marketing systems resulting in low prices at the producer level
- Destruction of gum and resin producing trees for firewood, fencing and fodder
- Insecurity in some of the producing areas interfere with gum collection, storage and trade
- Low production of gum arabic due low adoption of best practices and land and tree tenure issues
- Low export volumes are partly due to lack of capacity to bulk enough quantities and lack of reliable suppliers
- Inadequate data on the resources, trade and marketing
- Lack of clear policies and strategies on development of gums and resins
- Inadequate incentives including access to credit by producers and traders
- Frequent and prolonged droughts affect gum production
- Un-regulated production system with collections from the wild resulting in unreliable supplies

Opportunities for Promoting Commercialization of gums and resins

- *Acacia senegal* var. *kerensis* gum from Kenya has high specific rotation, high nitrogen content and a high molecular weight compared to the *Acacia senegal var senegal* gum and can be used as a food dietary fiber, a stabilizer/ thickener in viscous food such as yoghurt, cheese, jam etc. This provides a niche market for Kenyan gum arabic
- The promulgation of the new constitution has opened new opportunities for all sectors including gums and resins sub-sector especially in the devolved governments
- County governments have an opportunity to develop a legal framework that will establish a county statutory board with the mandate to oversee investment and development of gums and resins sub-sector in each producer county.
- Operationalization of the gums and resins rules, currently under development, would help in streamlining the sub-sector
- The Forest Conservation and Management Act 2016 also has provisions that can support the development of the sub-sector

- Presence of NGARA secretariat in Kenya can help in providing useful linkages and market access
- At least 3 cooperative societies exist that could be used to market gums and resins
- The demand for gum resins from Kenya in the export market is higher than the supply
- Development of market information systems on market access, requirements and price trends
- Strengthening GARA by supporting implementation of the 2016-2020 strategic plan would be a starting point in reforming the sub-sector. A strong GARA would lobby the government for enabling policies and assist them in the establishment and strengthening of the producer associations
- Strengthening of producer associations/cooperative societies would help the local communities' access credit and negotiate for better prices in line with prevailing market prices
- Value addition through establishing medium processing plants (steam distillation or extraction plants) that will result in export of semi processed commodities
- Establishment of plantations and promotion of management practices for the trees in the wild

Conclusion and Way Forward

The major barriers that limit the realization of full potential for the gums and resins in the dry lands of Kenya have been identified and classified as ecological and climatic issues, socio-economic factors, technological barriers and policy as well as institutional barriers. These have led to low exports of the commodities relative to the resource potential. Challenges of low export volumes are also partly due to inadequate capacity for production and value addition, incapacity to bulk enough quantities, lack of reliable suppliers and weak market linkages. It is therefore necessary to mitigate the identified challenges and take advantage of the existing opportunities to commercialize the gums and resins production and trade for improved livelihoods of vulnerable producers/collectors.

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Status of Bamboo Development in Kenya

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Abstract
Most of the bamboo resources in Kenya comprise one indigenous species, *Oldeania alpina,* which was formerly known as *Arundinaria alpina* and more recently *Yushania alpina*. The current distribution of the species is in the highlands of Mau, Mt Elgon, Cherang'any, Mt Kenya and the Aberdares. The area coverage is about 140,000 ha down from 450,000 in 1960sha. This reduction was due to unsustainable conversion of forest land into agricultural land and it lead to a Presidential ban in 1982. As a result of this ban, KEFRI sought to introduce 22 exotic species from Asia in various ecological zones in the country and over 10 species were successful. This paper looks at bamboo production, management and achievements in areas of research. It will also highlight the opportunities in commercialization of the natural and planted bamboos. Lastly it looks at the policy considerations and proposed strategies in the development of this sector.

Keywords: Bamboo management, bamboo development, *Arundinaria alpina, Yushania alpina, Oldeania alpina,* Kenya

Introduction

Bamboo belongs to the grass family and is the fastest growing plant that generates substantial amounts of biomass within a short period of time. It is a versatile species with multiple economic and ecological benefits. Most of the bamboo resources in Kenya comprise one indigenous species, *Oldeania alpina,* which was formerly known as *Arundinaria alpina* and more recently *Yushania alpina*. It is believed that Kenya once had bamboo forests covering over 450,000 hectares (Kigomo, 2007). Currently the bamboo forest covers 140,000 ha (Zhao *et al.* 2017) with the *Aberdare Range* having the highest bamboo cover (50,038 ha) followed by Mt Kenya (25,966 ha) (Figure 1). The bamboo forest in Kenya is mostly found in an altitude between 2200 m and 3300 m above mean sea level (MASL). This indigenous bamboo is important in the protection of the water catchments and also as an important habitat for the mountain bongo antelope.

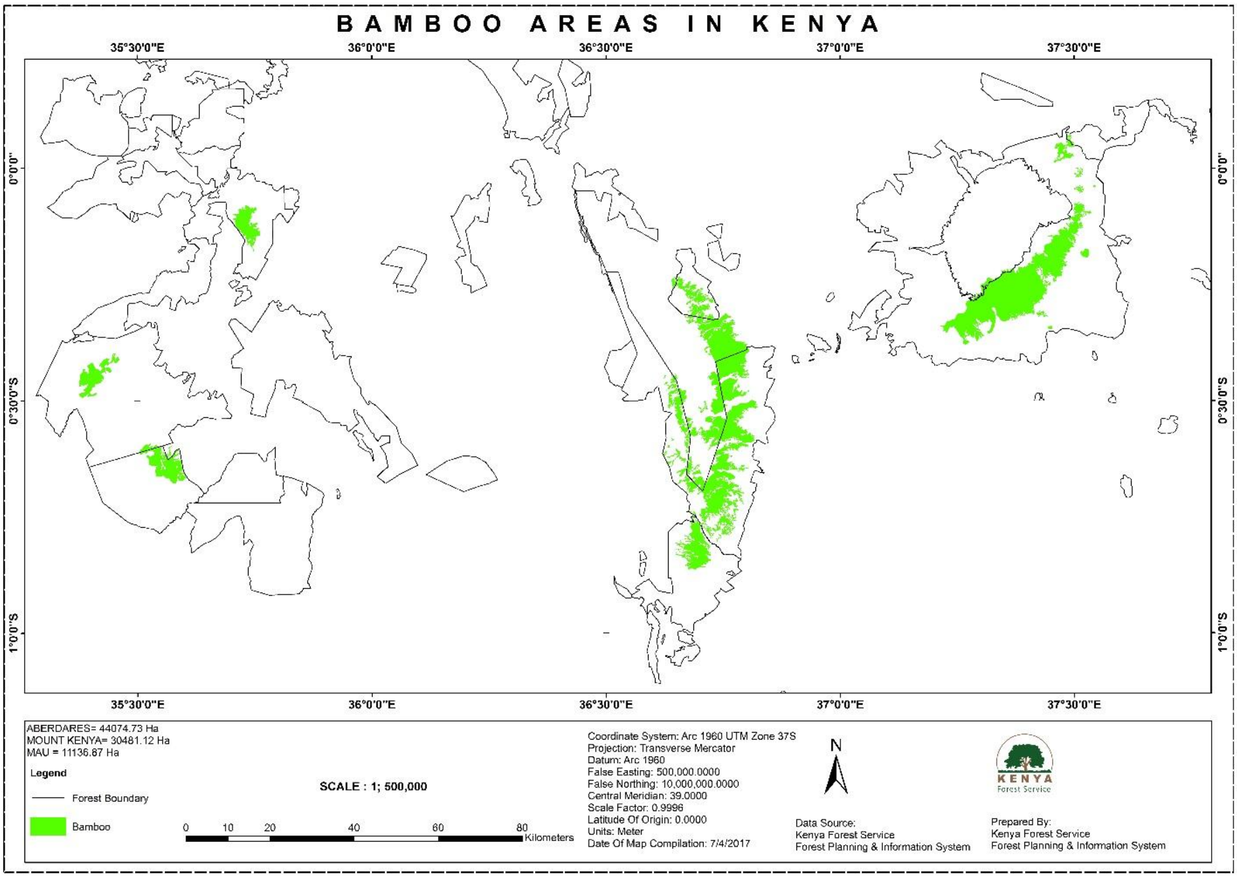

Figure 1. Map showing the areas with indigenous bamboo (Source: Zhao *et al.* 2017)

In 1982, as an effort to curtail further destruction of bamboo, the President issued a directive restricting the cutting of indigenous bamboo. The ban was also to allow the over-cut areas to regenerate to their full potential. However, local farmers, small enterprises and the horticultural industry continued to use the bamboo under controlled licensing. After the ban, The Kenya Forest Research Institute (KEFRI) initiated a program to investigate the potential of bamboo and to develop strategies for its cultivation and utilization in Kenya (Kigomo, 1988; Kigomo 2005). Over 40 bamboo species were introduced in the 1980s from Asia and tested in various regions in Kenya including the Lake region (Kakamega), the Highlands (Muguga), and the Coastal (Gede and Jilore-Malindi) regions. These successfully introduced species are more versatile and can be cultivated in areas where the local bamboo does not thrive. The species include: *Bambusa bambos*, *B. vulgaris* "vitatta" *B. tulda*, *Dendrocalamus hamiltonii*, *D. brandisii*, *D. membranaceus*, *D. strictus*, *Cephalostchyum pergracile*, *Thyrsostachys siamensis* and *Oxytenanthera abyssinica*. Farmers, horticultural flower farming companies, and various private companies have expressed great interest in growing these bamboo species on their land.

This paper looks at the development of this sector since the introduction of the exotic species. It, outlines the successes in the area of production, management and research. It also addresses some of the opportunities in bamboo commercialization and policy, challenges and proposed strategies in the development of this sector.

Bamboo Production

The uses of bamboo include water catchment protection, carbon sequestration and as an alternative to wood for construction, furniture and energy needs. These multiple uses have contributed to its great demand in Kenya. Bamboo resources in the country contributes to the local livelihoods with an estimated total of 3.2 million culms being used for fencing, construction, props in the flower industry, edible shoots, tooth picks and skewers, incense sticks, baskets and handicrafts (Ongugo *et al*., 2000). A study carried out by KEFRI indicated 68 % of bamboo culms are either old (60 %) or dead (8 %) and are therefore suitable for immediate use (Muchiri and Muga, 2013). The study suggests that 50 % of the culms of a bamboo stand comprising the dead and old stock can be harvested without negatively affecting the environment. Based on this study, some companies have expressed interest in using large amounts of bamboo for production of various products including bio-energy, panels, particle boards and pulp. Bamboo production in Kenya is quite low given that the African Highland Bamboo, *Oldeania alpina* is the only native species, which grows naturally. After the introduction of the exotic species a number of farmers and entrepreneurs have planted bamboo. Some of the counties where bamboo has been introduced are Migori, Homa Bay, Siaya, Vihiga, Kakamega, Busia, Kisumu, Narok, Kericho, Nyandarua, Murang'a, Kitui, Makueni, Machakos and Kilifi.

KEFRI has also trained groups of farmers in a Kitui, Makueni, Busia, Migori, Kakamega and Kericho counties on bamboo propagation and management. Different community based organizations, companies, individuals and private firms are involved in bamboo propagation and production e.g Tiriki Tropical Gardens, Bamboo Trading Company Limited (BTCL), Green Pot Enterprises, Eco Green, Kitil Farm among others.

Bamboo Management

Status

Kenya has a history of restricted utilisation of bamboo for industrial purposes in Mt Kenya Ecosystems Management Plan (2010-2019) and the Aberdares Ecosystems Management Plans (2010-2019) provide for the development of bamboo resources. In particular, the plans provide for the "*bamboo development programmes*" are in line with management objectives of the plans. The plans also note that given bamboo dies up after it attains it biological age, the accumulation of the dry dead material is usually a recipe for forest fires which are very difficult and expensive to control. Further, the plans note that due to its high rate of regeneration, the controlled exploitation of bamboo has no negative impact on the catchment value of the forest ecosystems. Therefore, the approval by the Board of Kenya Forest Service to allow industrial utilisation of bamboo in natural forest areas marks a turning point in the way bamboo resources should be managed.

Key constraints

The dead and fallen bamboo culms that are of no economic value due to lack of management in the bamboo forest are a source of forest fires.

Opportunities

At present, East Africa's bamboo sector remains largely untapped, despite the region having sub-Saharan Africa's largest natural bamboo forests and accounting for around 3 to 4 % of the world's total bamboo coverage. The global export trade in bamboo products is valued at over US$30 billion. The undisturbed bamboo stands of the indigenous species have 10,000 to 17,000 culms ha^{-1}. The opportunity to sustainably harvest and manage these resources is evident. Currently a guideline on harvesting and management of indigenous bamboo in Kenya is in a draft stage. This guideline will provide for the silvicultural and administrative management procedures in the harvesting bamboo culms from *Oldeania alpina* stands in natural the forests anda suitable method of assessment of bamboo culms for purposes of selling.

Bamboo Research

Achievements in areas of research

There are some achievements in the area of research over the years. After the successful introduction of exotic bamboo species performing well in various agro-ecological areas there have been other investigative activities that have been undertaken by various entities. In 1999 KEFRI undertook a case study on bamboo Production-to-Consumption System looking at the product and market information regarding the many uses of bamboo. A study on Preservation of *Yushania alpina and Oxytenanthera abyssinica* culms against subterranean termites and fungi in Ethiopia and Kenya was carried out from 2007 to 2012. Another collaborative project investigating the nutritive components of bamboo shoots of two bamboo species was undertaken by a multidisciplinary team from ISAAA, JKUAT, KEFRI and TBPT from 2010 - 2013. The third study determined the factors that influence the development of bamboo value chain in Kenya was undertaken between 2011 and 2014. The study looked at growth performances of bamboo in tobacco growing regions in South Nyanza (now comprised of Migori and Homa Bay Counties), Kenya. This project aimed at diversifying the livelihoods of small holder tobacco farmers (Kibwage *et al.*, 2008).

Studies on its potential as a source of bioenergy have been carried out by Katumbi *et al*., 2017; Green Belt Movement has a bamboo biomass and entrepreneurship project in Murang'a County (Green Belt Movement, 2014). A study by Finlays, a tea processing company, investigated bamboo as a fuel in boilers for tea processing in 2012. The study looked at boiler efficiency using bamboo compared to Eucalyptus billets.

Future/Opportunities

Strategic research is needed to provide technical information on the local bamboo resource in order to guide on its management, harvesting, marketing and utilization. Research is needed to:

- Intensify production from existing bamboo plantations
- Expanding bamboo production to private farms
- Improving and diversifying use of bamboo resources
- Developing comprehensive extraction techniques and harvesting regimes

- Developing techniques for restocking over cleared bamboo areas.
- Developing management practices in respect to harvesting regimes for various bamboo species under cultivation.
- Improving knowledge on local bamboo properties to enhance diversification of utilization
- Developing effective bamboo treatment methods to increase period of usage.
- Assessment of marketing dynamics as a feedback to investment in the bamboo industry. Technology transfer - Develop a proposal on KEFRI regional demonstration centres on bamboo.

Key constraints

Some of the key constraints include: Inadequate funding to facilitate bamboo research and development; inadequate technical knowhow for bamboo processing research; Lack of high level technology equipment for research; and Lack of coordination among different stakeholders in bamboo research and development in the country.

Opportunities

Opportunities in research exist for we have a wide ecological range of introduced species; availability of technical backstopping in-terms of skills and machinery for training on processing and business incubation at KEFRI centres in Karura and Londiani; the existence of the Forest Conservation and Management Act 2016 (section 44) which supports areas of production (Concession on public forests); the Kenya Vision 2030 which promotes industrialization and enhanced tree cover. Bamboo can contribute immensely towards this blue print. In addition, the Constitution of Kenya supports environmental protection.

Sustainable Commercialization of Bamboo

Studies indicate more than 1000 different products can be manufactured from bamboo and this has led to successful and viable industries in other developing countries such as India and China. The main use of *Oldeania alpina* bamboo in Kenya is construction and fencing. There is high demand for bamboo for use in horticulture farming, handcraft, residential fencing, and cottage industry for making furniture, baskets, tooth picks and match sticks. Horticultural companies use Bamboo in their flower farming activities. Studies in year 2000 indicated that only about 0.06 % of bamboo is from farms, and out this, the farmers get about KES 6.7 million. The Government loses about 83% of potential revenue to poachers, translating to about 94 million at the present royalty rate of KES 100 per culm and 33 per kg of shoots. If the value of culms at the Hardware shops is taken as a guide, then the current Kenyan bamboo economy is more than KES456 million annually. Of this amount, only about 12 % accrues to the Government as revenue (Omari, 2009).Due to fast growth and high regenerative capacity, alongside low initial investment, bamboo can substitute timber, in many cases, with no environmental concerns normally associated with logging. Indeed, a study by Brias (2006) indicates profits from bamboo plantation can be generated in year 6 of plantation establishment and the cumulative pre-tax profit can be realized at the end of year 7, showing that the payback of investments is attainable in year 7. This is far shorter than the average 25-

year rotation for plantation of pines or cypress for timber. Further, Brias (2006) showed that if bamboo is intended strictly for use as biomass, then it could be more cost competitive than eucalyptus.

Bamboo commercialization initiatives inside gazetted forests

A study carried out by KEFRI indicated that 68 % of bamboo culms are either old (60 %) or dead (8 %) and are therefore suitable for immediate use (Mbae and Muga, 2013). The study suggests that 50 % of the culms of a bamboo stand comprising the dead and old stock can be harvested without negatively affecting the environment. Based on this study, some companies have expressed interest in using large amounts of bamboo for production of various products such as bio-energy, panels, particle boards and pulp. Kenya Forest Service (KFS) has licenced two companies (Bamboo Trading Company and Green Pot Enterprises) to utilize bamboo from the gazetted forests while growing their own for the industries that they are putting up. Kenya Forest Service (KFS) granted Bamboo Trading Company Limited (BTCL) a Special Use License to undertake a bamboo biomass feasibility study on 25 hectares of Aberdare Forest Reserve. The KFS has allocated 5,000 hectares of bamboo forests within the Aberdares and Mt. Kenya forests to Green Pot Enterprises for selection and sustainable harvesting in order to secure the initial feedstock for two bamboo processing factories under the terms and conditions of KFS. Table 1 highlights the progress of these special licenses to the two processing companies.

Table 1. Progress of license execution for 2 processing companies licensed by KFS

Name of company	Date of the license	Purpose of the licence	Licensed area	Progress of license execution
Bamboo Trading Company Ltd	25th April 2012	• Feasibility study for power generation from bamboo • Promote bamboo growing for conservation & biodiversity protection • Establish primary industry for socio-economic development • Promote propagation of bamboo for commercialization	Kieni and Ragia forest stations in Aberdares	• Feasibility study completed in the initial 25 Ha • An additional 475 Ha granted to expand trials and set up demo sites for commercial bamboo for provision of energy as either chips or cross cut culms • An addendum (valid for 5 years from 25th April 2012) was granted and may be subject to renewal. • A bamboo processing depot and a tented camp constructed outside the forest
Green Pot Enterprises Ltd	18th October 2016	• To secure the initial feedstock for two (2) bamboo processing factories. • Joint management of tree nurseries with a target of between 5-10 million bamboo seedlings per year.	Aberdare and Mt Kenya ecosystems	• The firm was allocated 5000 Ha in the two ecosystems. • Mapping and assessment of the resource is ongoing. • Site for the processing factory identified and EIA done. • A sample of bamboo taken to China and KEFRI for advice on the potential products. • A bamboo nursery initiated in Nyeri and Narok with a stock of over 1 million seedlings. • Contract farmers identified for the bamboo outreach programme.

Bamboo commercialization initiatives outside gazetted forests

Commercialization of bamboo outside gazetted forest is slowly gaining currency, and various institutions, including county governments have taken up the initiative for example Nyandarua County Government and Ewaso Nyiro South Development Authority has also taken up bamboo commercialization (Table 2). There are also other on-going bamboo commercialization initiatives involving CBOs, cooperatives and individual farmers at various stages of development.

Table 2. Bamboo commercialization by Ewaso Nyiro South Development Authority

Start date	Objective	Area of operation	Progress
2013	To improve livelihood and enhance socio-economic development in the basin through bamboo farming and processing for value addition, revenue generation and employment creation	Narok, Bomet, Nakuru, Nyandarua & Kajiado	• Bamboo seedling production commenced in 2013 using greenhouse technology. • ENSDA staff trained by KEFRI and are now undertaking the seedling production

Key Constraints in bamboo commercialization

The key constrains can be categorised as policy, legal, management, technology and market related constraints as enumerated in Table 3.

Table 3. Key constraints for bamboo commercialization

No	Category	Issues
1	Policy	• The previous ban on exploitation of bamboo led to underdevelopment of the bamboo species across the entire value chain. • Although the ban has since been lifted, the impact is still being felt
2	Legal	• The uptake of devolved forestry functions by the county governments is yet to take place. This includes development of bamboo outside gazetted forests. • Despite preparation of 47 Transitional Implementation Plans, only 2 have been signed and are yet to be implemented.
3	Management	• Technical challenges in propagation of bamboo has hampered production of adequate seedling stocks • The issuance of movement permits for bamboo is bureaucratic and the procedure is unclear to many field officers. • County governments who have the responsibility of issuing movement permits for intra-county bamboo products are yet to take root due to inadequate capacity and non- operationalization of TIPs. • Multiple payment of cess fees for a single load during inter-county movement of bamboo and other forest. • Inadequate bamboo management and harvesting guidelines to guide field officers.
4	Technology	• Inadequate technology in harvesting and processing of bamboo
5	Marketing	• Inadequate information on demand for bamboo services and products. • Inadequate awareness on the ecological, environmental and economic benefits of bamboo. • Lack of organized marketing structure such as timber manufactures associations, charcoal producers etc.

Opportunities for Bamboo commercialization

The last decade has seen increased focus on bamboo as a solution to address ecological, environmental and economic challenges. There are various opportunities in the bamboo development that has resulted in increased interest in the species as tabulated in Table 4.

Table 4. Opportunities for Bamboo commercialization

No	Category	Opportunities
1	Policy & legal	• Kenya Vision 2030 which is the government development blue print has identified bamboo development as one of the flagship projects thus elevating the status of bamboo among the government priorities • Forest Policy 2014 calls for diversification of species range outside the traditional forest plantation species • The Forest Conservation and Management Act 2016 has identified bamboo as one of the key species that should be promoted.
2	Management	• KFS is promoting development of bamboo value chain through issuance of licences and encouraging farmers and private organization to invest in bamboo development
3	Technology	• Exposure of government staff and private individuals to technology in countries that have advanced processing and utilization of bamboo e.g. China • Local research and development of appropriate technologies for bamboo processing and utilization e.g. KEFRI & JKUAT
4	Market	• The ban on polythene bags has created a market for biodegradable material which can be sources from bamboo • The wood, pulp and construction supply deficit in the country can be bridged by bamboo products • Entrepreneurial opportunity based on new products from bamboo such as food, beverage and clothing

Instruments for Public-Private Partnerships (PPP)

A Public Private Partnership is defined as being an agreement between a public entity and a private party. Based on the challenges identified and the existing opportunities, the PPP provides a good avenue as a driver for commercialization of bamboo. Under the government structure, there are inherent limitations when it comes to business and commercial development, thus the PPP offers a better option for commercialization of bamboo. Tabulated in Table 5 are the instruments for PPP.

Table 5. Instruments for Public-Private Partnerships (PPP)

No	Category	PPP Provisions
1	Legal	• The government has enacted the PPP Act 2013 that guides the modalities of engaging and implementing of PPP. • The Forest Conservation and Management Act 2016 has a clear provision for engaging the private sector through: – Joint Management Agreement – Contract – Special Use License – Concession
2	Administrative	• The government created a PPP committee and a unit to facilitate and fast-track the undertaking and finalization of PPP agreements.
3	Management	• The National Forestry Programme (NFP) and KFS Strategic Plan (2017-2022) provides for PPP engagement as a catalyst to forestry commercialization.

Way forward in commercialization of bamboo

1. The Transition Implementation Plans (TIPs) should be expeditiously signed and implemented in order for the county governments to take up their rightful roll and obligation in forest conservation, including bamboo conservation and management
2. Transfer of technical knowledge and information to the frontline managers from KFS and counties should be prioritized for effective technology transfer and implementation.
3. KFS should streamline and clarify the modalities of issuance of movement permits to the field staff with a view to simplifying the procedure.
4. County governments should enhance their capacity for the devolved forestry functions to enable them implement their functions as stipulate in various statutes.
5. A national policy which will address cess collection procedures from the point of origin of the forest product to the destination should be developed. This will address the challenge of multi-payment of cess fees for a single consignment during inter-county movement of tree products.
6. KFS to finalize preparation of bamboo conservation and management guidelines which will guide field staff in bamboo management.
7. Enhance the knowledge and technology transfer of bamboo development and management in order to promote bamboo commercialization by the stakeholders.
8. Institute a national demand-supply survey of various bamboo products and services. This will include the review of the current status and make projections for the future requirements.
9. Encourage formation of a bamboo association that brings together the entrepreneurs and farmers to support organized commercial bamboo trade.

Some Key Policy Considerations for Kenya

Need for bamboo policy

Undoubtedly Bamboo can revolutionize the economy of some parts of Kenya ensuring employment opportunities to a large number of people. To achieve this, progressive policy on bamboo need to be developed. The draft policy currently under discussion gives a renewed thrust to extension and awareness about bamboo sector development.

The Strategy

The development of Bamboo in Kenya could be approached in two approaches:

a. Development of Bamboo as a Resource
b. Development of Bamboo as an Enterprise.

Resource scenario of bamboo

There is one species of indigenous Bamboo, Oldeania alpina occurring in Kenya and is abundantly found at altitudes of between 2400 and 3000 m. There are other species introduced in the country, one of which is very common. Data on the O.alpina resources are available. However, data on farm hasn't been quantified

Suggested aims and objectives of a new bamboo Policy

Considering the Ecological significance and vast economic potential of Bamboo in Kenya, aims and objectives of the draft Bamboo Policy are:

1) Protection and preservation of mountain ecology; protecting the mountain slopes by affording protection to bamboo forests and bamboo regrowth areas for sustained productivity and environmental security for the people.
2) Protection and conservation of bio-diversity associated with bamboo forests and regrowth areas and their future development.
3) Sustainable development and utilization of Bamboo resources through scientific management.
4) Promotion of private bamboo plantation (individual and community owned) as the key thrust area for future economy of the adjacent communities.
5) Promotion of bamboo cultivation in the homestead and as a cash crop and an essential component of agro- forestry to generate income and to meet the contingent need of rural households in the adjacent community.
6) Improvement of bamboo productivity in farm and forestry sector through improved management practices thus making bamboo plantation a profitable and attractive economic enterprise for securing adequate return on investment.
7) Promotion of bamboo based industries at cottage level, small, medium and large scale for utilizing the available resources at a sustainable level for generating assured income.
8) Promotion of Bamboo craft and art with improved technology, design and market linked trade for value added items for export through industrialized mode of production.

9) Promotion of bamboo sector development as an essential component of rural development strategy linked with forestry and agri-business sector promoting rural employment and enhancing household incomes.

10) Promotion of bamboo as an essential wood substitute by increasing bamboo production. Promotion of enterprises manufacturing bamboo based products and wood substitutes thereby reducing pressure on forests and reducing the already high wood deficiency in the country.

11) Promotion of awareness and understanding of bamboo as "Green Gold" among farmers, traders and industrialists in the country with a view to utilizing its full potential and to galvanize the rural and industrial sector in the country.

12) Promotion of research support for the bamboo sector to improve quality, enhance productivity and value of products, sustainable management, and conservation of germplasm.

Conclusions

- Bamboo has a great potential to enhance community livelihoods in Kenya while also enhancing environmental conservation hence the need to increase production. Increasing bamboo production will contribute towards increasing the green cover in Kenya. This calls for sustainable management, conservation and utilization of existing bamboo resources in gazette forests and more planting in communal and private lands.
- Establishment and management of bamboo in Kenya are by the following challenges: competing farming activities; highly restricted range of Kenyan Bamboo; poorly developed market for bamboo products and inadequate information and training on in-situ management which would allow sustainable harvesting. The bamboo is also affected by browsing by animals, inadequate supply of planting material for all stakeholders and high cost of protecting bamboo trials.
- A major drawback for the development of the bamboo sub sector is the Presidential ban on harvesting from public forests. The harvesting ban, its legality notwithstanding, is costing the Government hundreds of millions of Shillings in lost revenue every year. Without an effective forestry audit system in place, controlled licensing creates opportunities for corruption.
- Due to fast growth and high regenerative capacity, alongside low initial investment, bamboo can substitute timber, in many cases, with no environmental concerns normally associated with logging.
- To make good use of bamboo resource in Kenya, some suggestions have been made on draft policy that ought to be considered. The draft policy places emphasis on the management of the resource and the need to promote bamboo agroforestry and plantations.
- To progressively use bamboo to improve the economy of the rural poor, there is need to implement the current draft policy.

Recommendations

1. It has been made very clear that Presidential Decrees and other pronouncements require a Minister, in whose docket the decree has been made to gazette the decree in order for such a decree to be legally binding. This has never been the case with the Presidential decree on preservation of bamboo, therefore upholding the 'ban' is technically illegal and unconstitutional. This illegality should be brought to the attention of the relevant Minister, not to regularize the ban through gazettement but to initiate a progressive bamboo policy development process realization.
2. There is urgent need for holding a highly interactive national workshop on bamboo, drawing participation from a broad range of stakeholders. The participants should include policy makers from the Ministry of Environment and Natural Resources, The KEFRI Board, The KFS Board and the Attorney General. Key presentations should be from a legal expert, bamboo resource specialist, and bamboo entrepreneurship expert from Asia and a natural resource economist at the very least. The objective of the workshop is to develop consensus on the status of bamboo as a natural resource and develop a road map for a comprehensive draft policy realization.
3. Pilot a small acreage of bamboo plantation within Kamae Division of Kiambu adjacent to the main road. The bamboo stand should be subjected to intensive silvicultural management. This plot should be used to demonstrate all the positive attributes of bamboo.
4. Establish the quantity of Bamboo on farms
5. Need to intensify research on bamboo production and utilization including a national demand-supply survey of various bamboo products and services.
6. Promote commercialization of bamboo
7. KFS to finalize preparation of bamboo conservation and management guidelines which will guide field staff in bamboo management
8. Enhance the knowledge and technology transfer of bamboo development and management in order to promote bamboo commercialization by the stakeholders.
9. Fast track signing and implementation of Transition Implementation Plans (TIPs) (with the Counties who haven't signed) in order for the county governments to take up their rightful role and obligation in forest conservation, including bamboo conservation and management
10. Encourage formation of a national bamboo association that brings together the entrepreneurs and farmers to support organized commercial bamboo trade.

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Characterising the Nutritional Composition of *Sclerocarya birrea* (Marula) Fruits in Kenya

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Introduction

Indigenous fruits play a crucial role in house hold income and food security of many communities in arid and semiarid areas. In addition, they are rich source of nutrients that includes carbohydrates, proteins, minerals, vitamins, fat and water (Hall *et al.*, 2002). *Sclerocarya birrea* locally referred to as marula is a medium size and a single stem deciduous tree. The tree belongs to a family of Anacardiaceae and has an average height of 10 meters (Wairagu *et al.*, 2013). In Kenya, it naturally grows in the semi-arid areas and is maintained in the farms in an agroforestry situation. Fruits are eaten fresh and have a sweet and refreshing taste. Benefits derived from this fruit tree are quite numerous as nearly all parts are exploited in the following ways:

a) Fruits are eaten fresh and its juice is rich in vitamin C and some minerals.
b) Extracted pulp is extracted and used for making wine, jam, jelly and juice and thus contributes towards nutrition, Livestock and wild animals feed on fruits and foliage:
c) Oil from kernel is edible and is also a popular ingredient for moisturizing and softening skin in cosmetic industry.
d) (b) Substantial medicinal importance is associated with this species such as bark and leaves are used to treat diarrhoea, ulcers and fever while roots are used for treatment of sore eye. The skin of the fruit is used to treat blisters caused by caterpillars
e) (c) Wood is used for carvings and fuel wood (Hall et al., 2002; Shackleton et al., 2002).

In central and southern Africa where it is also found in plenty, commercial products are produced for export with significant benefits to rural communities (Hall *et al*., 2002).

Figure 1. Intercropping *S.birrea* with maize in Mbeere

Figure 2. Ripe fruits being picked

Figure 3. Fresh fruits

Objective

The aim of this study was to carry out nutrient contents of *Sclerocarya birrea* fruits as one of the Kenyan drylands indigenous fruits with a high potential.

Methodology

Mature fruit samples were collected from Mbeere in Eastern part of Kenya and analyzed for the nutritional composition. The analysis carried out included energy, moisture, ascorbic acid, proximate and minerals (i.e. Ca, Mg, K, Cu, P, Fe and Zn). Flame atomic absorption spectrophotometer (FAAS) was used for elemental analysis (AOAC ,1990). Ultra Violet-visible spectrophotometer (UV/VIS.) for quantification of phosphorous (Okalebo *et al*, 2002), Kjedahl method for crude protein analysis, bomb calorimeter for internal energy and soxhlet method of analysis for crude fat while various classical methods of analysis were employed for the other parameters (AOAC ,1990).

Results and Discussion

Table 1. Summary of nutritional composition of edible portions

Parameter	Pulp	Kernel
Dry matter (%)	12.73± 0.26	93.01±0.78
Total ash (%)	3.5±0.53	1.59±0.34
Ascorbic acid (mg/g)	1.90± 0.081	--
Fat (%)	0.34± 0.04	54.1±0.95
Protein (%)	3.58±0.14	30.34±0.30
Energy (kJ/g)	17.92±0.27	30.36±0.04

Table 2. Concentration of mineral elements in the edible portions

Parameter	Pulp	Kernel	Detection limit
K (µg/g)	32203.6 ±43.2	4866.36 ± 25.95	0.378
Ca (µg/g)	6884.58 ± 207.39	4489.6± 185.9	0.012
Fe (µg/g)	27.92 ±2.6	44.62 ± 0.89	0.0226
Mg (µg/g)	1585.12± 10.44	2537.64 ±19.38	0.048
Cu (µg/g)	3.2± 0.75	17 ± 2.57	0.638
Zn(µg/g)	23.25±0.3	44.71± 1.4	0.063
P (µg/g)	1456.34	1607.38± 26.44	0.0103

The results of analysis indicated that the kernel was rich in fat, energy, protein, Potassium, Phosphorous and Calcium. Pulp on the other hand, had significantly high levels of ascorbic acid, Potassium, Phosphorous and Calcium. However, Iron, Magnesium, Zinc and Copper were present in low quantities (Wairagu *et al*, 2013). The above results compare well with oranges as one of the exotic fruits. Ascorbic acid level of *S. birrea* (190 mg/100 g) was significantly higher than in oranges (48.5 mg/100 ml). In terms of minerals oranges contain 179 mg/100 g, 40 mg/100 g and 10 mg/100 g for potassium, calcium and magnesium respectively (USDA national nutrient data base) meaning that *S. birrea* fruits have more appreciable amount. Energy, fat and protein results from the kernel also compare well with red beef that contains 23.5 % protein, fat 2.8 % and 498 Kj/100 g energy (Peter, 2007).

Conclusion and Recommendation

The above results indicate that the fruits have great potential as a source of essential nutrients especially in arid and semi-arid lands. It was found to be rich in energy, minerals, fat, protein, carbohydrate and vitamin C which are important in human diet.

It is recommended that parameters such as vitamin B complex, tocopherol (vitamin E), water insoluble and soluble ash and chemical composition of the kernel oil be determined. The technologies developed by KEFRI for value addition need to be transferred to communities where this resource is found to give them an opportunity to explore for more benefits by enjoying increased resources and improved quality of their diet. However, this recommendation does not necessarily have to be applied right away due to financial constraints.

Acknowledgments
We are grateful to the Jomo Kenyatta University of Agriculture and Technology and Kenya Forestry Research Institute Technical staff in the laboratories for the assistance they offered during analysis. Thanks to Peter Njeru for his assistance as a field guide during the fruit collection in Mbeere.

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THEME 5: INFORMATION AND KNOWLEDGE MANAGEMENT

Open day at Muguga

Training of stakeholders

Evaluation of Extension Methods in Forestry Development Suitable for Increased Information Dissemination of Forestry Technologies and Innovations in Kilifi and Kwale Counties, Kenya

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Abstract

Ineffective linkage between forestry research and extension has led to disruptions in technology flow, and hence low adoption rates, increased time lags between development and adoption of new technology leading to low forest development and inadequate forest contribution to community livelihood. The study sought to identify effective dissemination methods for increased information dissemination of forestry technologies and innovations in Kilifi and Kwale Counties. Questionnaires were administered to 100 farmers and other stakeholders who are the key recipients of KEFRI's scientific findings including government agencies, NGOs and farmers. Focus Group Discussions were undertaken with key informants. The sample units of farmers and stakeholders were randomly selected. The farmers were categorized based on the crops and/or trees that they grow. Data was subjected to Analysis of Variance (ANOVA) using SPSS. Results from the study indicated that 60 % of the respondents preferred demonstration plots method of disseminating forestry technologies with print media platforms being the least preferred. Farmers and stakeholders indicated that through the demonstration plots they were able to learn and apply the technologies directly on their farms. The results of this study will guide in the development of forestry extension strategy, guide effective resource use and development of more effective dissemination platforms and methods.

Key words: Forestry extension, Dissemination, demonstration plots, Farmers

Introduction

Forestry occupies a strategic position in the economic development of most developing countries. To achieve a high standard of forestry development, a country must have strong research and extension systems. Nevertheless, despite the availability of highly productive and remunerative technology, a wide gap exists between research findings and what average farmers obtain from their land. The flow of information from forestry research to local farming communities and vice versa therefore requires that continuous contact be maintained by extension officers to be able to make information comprehensible to farmers.

Information dissemination is one of the components supporting forestry development, it is in turn supported and affected by the quality of forestry research and the degree to which policy and economies promote the adoption of new technology. In an aggregate sense, extension can be illustrated as the link between research and stakeholders.

In the coastal region of Kenya, it has been observed that the research being carried out is not making adequate impact on the farmers and other stakeholders in the forestry development. The community's uptake on forestry technologies has not improved over a period of time, probably due to inadequate information. The purpose of this study was to identify effective dissemination methods for increased information dissemination of forestry technologies and innovations in Kilifi and Kwale Counties.

Materials and Methods

Study Area

The research was carried out in Kilifi and Kwale Counties. Kilifi County has an annual rainfall ranging from 300 mm in the hinterland to 1,300 mm at the coastal belt. The coastal belt receives an average annual rainfall of about 900 mm to 1,100 mm with marked decrease in intensity to the hinterland. The annual temperature in the County ranges between 21°C - 30°C in the coastal belt, and between 30°C and 34°C in the hinterland. Kwale County has an average annual rainfall of 400 – 1200 mm and an average temperature of 24.2°C (Kwale county website). The specific sites covered in the the study were Mtwapa, Magarini and Ganze in Kilifi County, and Samburu and Taru areas in Kwale County.

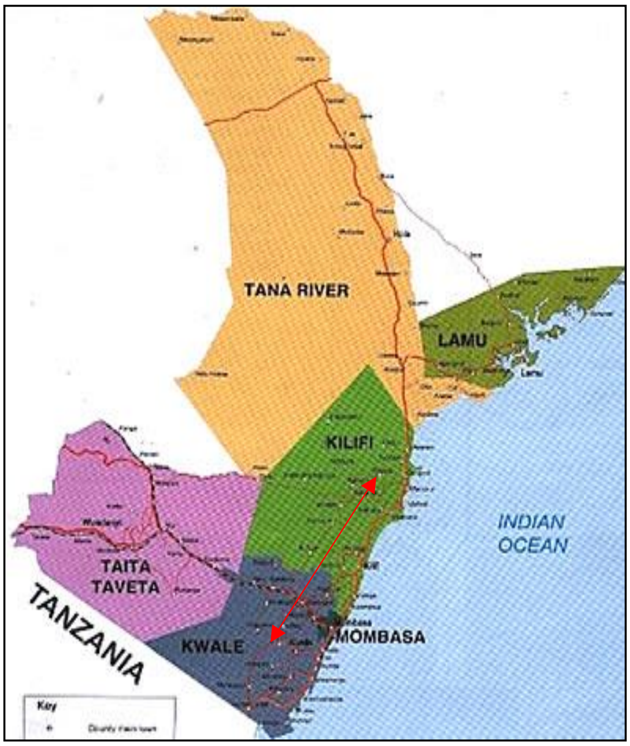

Figure 1. Kwale and Kilifi Counties of the Coastal Region of Kenya

Research Methodology

Stratified random sampling technique was used. Stratification was based on stakeholder groups such as Kenya Coastal Development Project supported farmer, local farmers, government institutions and Community Based Organizations involved in forestry. Random representative sample population (at least 4 replicates) from each category was taken. Purposive sampling was used to select study sites with different tree technology adoption rates and responsiveness to dissemination activities for comparative analysis. Mtwapa, Magarini and Ganze in Kilifi County, and Samburu and Taru areas of Kwale County were selected. Mtwapa and Ganze have very low tree technology adoption rates and similarly low responsiveness to dissemination activities held in the area, while Magarini have high tree technology adoption rates and high responsiveness to dissemination activities. Samburu and Taru have only recently adopted on farm tree farming following the Kenya Forestry Research Institute's intervention, but have been very responsive to dissemination activities. A comparative analysis of the different scenarios would provide an understanding of the most appropriate dissemination platforms in the areas as well as the factors affecting tree adoption rates in the different areas.

Purposive sampling was further used to select Kenya Forestry Research Institute's woodlot beneficiaries and those who had been involved in various dissemination activities, while simple random sampling was used to select non-beneficiaries, as well as those who had not attended any dissemination activity. Questionnaires were administered to the individual respondents, while key informant interviews were held with stakeholders, mainly officers from Kenya Forest Service, Ministry of Agriculture and Community Based Organizations with whom Kenya Forestry Research Institute has been collaborating with. Focus group discussions were held with extension officers and community groups. A total of 100 farmers were interviewed in the two Counties and two focus group discussions held.

Data analysis

Statistical Package for Social Sciences and Microsoft Excel were used to analyze the data. The data collected during the survey using the questionnaire responses was analyzed using Microsoft Excel for descriptive statistics and Statistical Package for Social Sciences for inferential statistics. Data was subjected to multiple regressions for analyzing relationship between variables and Analysis of Variance for analyzing differences among variables.

Results and Discussion

Land ownership

Land across the two counties is communally owned (74 %) and acquired mostly through inheritance in clans or family set-ups. There were no ownership documents or agreements for land acquisition. Cases of squatters in the two counties were widespread and insecurity of land ownership has been a hindrance to farmers investing in tree farming. Figure 2 indicates the ownership status of land in Kilifi and Kwale Counties.

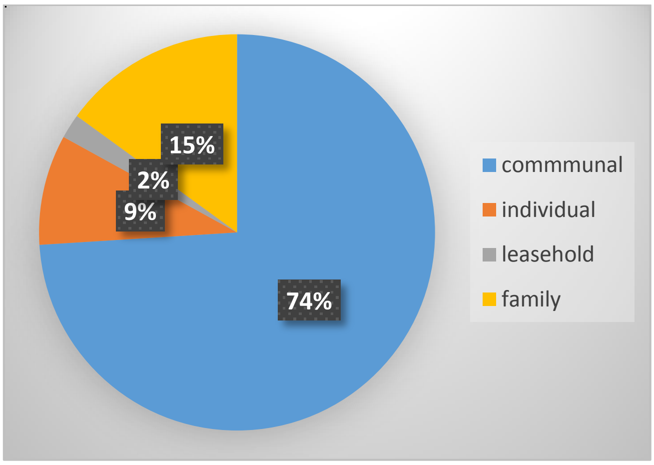

Figure 2. Land ownership in Kwale and Kilifi Counties

Livelihood sources

The main source of livelihood for the farmers is agriculture, although production still remains low, and its contribution to the household income has been decreasing over the years. Samburu and Taru areas of Kwale County are in the semi-arid zone, and are characterized by grassland and shrubs. Livestock keeping is the main agricultural practice in the area, with small scale crop production being practiced. The area has vast tracks of bare and degraded land that the livestock depend on for grazing. In Mtwapa, the land is characterized by fertile agricultural soils and the climatic conditions are favourable for tree farming. The main source of livelihood in the area is crop production. Farmers in the Mtwapa have small tracts of land due to the high population, but with high crop productivity. The main livelihood activities are indicated in Figure 3.

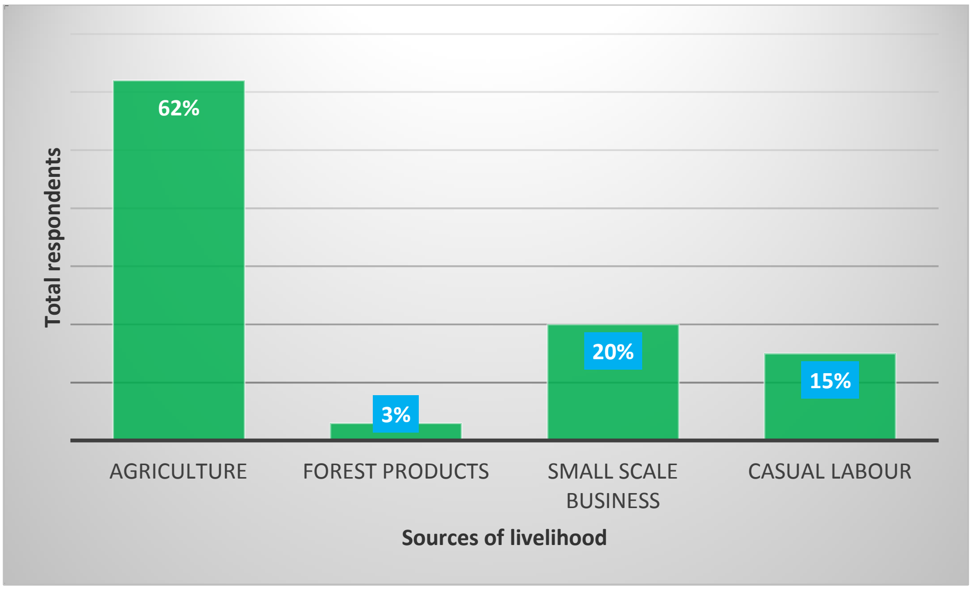

Figure 3. Household livelihood activities Kwale and Kilifi Counties

The preferred forestry dissemination platforms

The most preferred method of disseminating forestry technologies cited by most respondents was through demonstration plots (Table 1). Farmers especially those supported through Kenya Coastal Development Project indicated that through this mode of dissemination, they are able to learn and apply the technologies directly on their farms. In Samburu and Taru, field days and demonstration plots were the most widely used and preferred dissemination platforms. Farmers in Samburu and Taru are often organized into farmer groups and trained on various agroforestry practices on-farm through demonstrations. Demonstration plots are well replicated in the region and forms an effective means of disseminating technologies. The involvement of local leaders mainly village elders and faith based leaders was emphasized to be key in mobilizing community members for various dissemination activities. In Mtwapa, the most preferred dissemination platforms were field days and public meetings. Farmers reiterated that for dissemination activities to reach a wider audience and have impact, community groups, including CBOs, should be actively involved in mobilization of farmers for field days, while village elders should be actively involved in mobilizing community members for community meetings. The preferred dissemination methods are summarized in the Table 1.

Table 1. Preferred forestry dissemination platforms

Preferred dissemination platform	Kwale & Kilifi Counties
Demonstration plots	56 %
Field days/ Open days	31 %
Trainings and seminars	8 %
Print media/TV and Radio	4 %

Challenges faced in tree farming

Casuariana equisetifolia is the most preferred tree species in Kilifi County, while in Samburu and Taru in Kwale County, *Melia volkensii* is the most preferred. *Casuarina equisetifolia* is mainly grown in Kilifi County due to the favourable climatic conditions for the species. The species is fast growing and produces quality poles that have a ready market in the area. *Melia volkensii* naturally grows in Samburu and Taru areas because of the favourable climatic conditions for the species. Kenya Forestry Research Institute has established woodlots of *Melia volkensii* in the area and this has also contributed to the increased awareness and promotion of the species. Respondents mentioned the main challenges faced in tree farming as;

i. Land ownership. Land is communally owned in most parts of the two counties; and this has been a hindrance to farmers investing in tree farming.
ii. Unfavourable weather conditions. The area is characterized by water scarcity and high temperatures especially in the semi-arid areas of Samburu and Taru, which has lowered survival rates for trees.
iii. High incidences of pests and diseases. Tree pest and diseases are a common problem in the two counties. The poor silvicultural practices and management of trees has further exacerbated the problem. This has led to low quality forest products, hence discouraging farmers from tree farming.
iv. Inadequate technical information on tree farming. Access to technical advice and information on proper tree management is a challenge especially to farmers who are far away from the Kenya Forestry Research Institute offices. This, coupled with the high

illiteracy levels has hindered dissemination of forestry technologies to the local communities.

Livestock and wildlife invasion and destruction

Cases of livestock invasion are rampant in both counties. In Samburu and Taru, livestock are kept under a free range system. Due to the degradation and depletion of vegetation cover, they invade farms and destroy few crops and trees. There are also cases of wildlife invasion on farms destroying crops and trees. These challenges are summarized in the Figure 4.

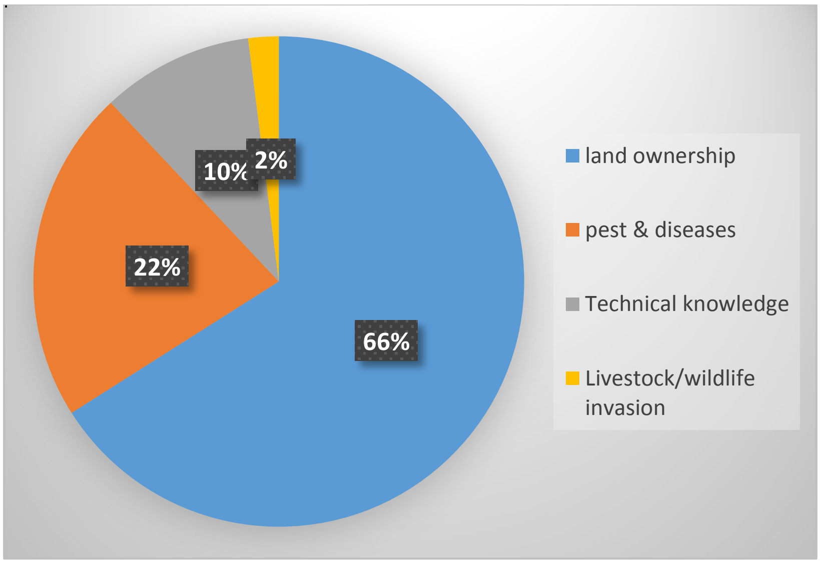

Figure 4. Challenges faced in tree farming in Kwale and Kilifi Counties

Suggested ways of improving technology dissemination

The following were the different ways of improving communication and forestry technology dissemination suggested by farmers;

i. Increasing the number of demonstration plots and field days. Farmers indicated that on-farm demonstrations are effective means of reducing the risks farmers perceive. The demonstrations serve to take new innovations out of the 'unreal', scientific realm of the research station and place them firmly within the bounds of a farmer's everyday experience. They are used first to display the results of adopting a new practice and then to give the farmer an opportunity to practice the new methods.

ii. Formation of farmer groups and famer field schools for tree planting. Farmers Field School is a non-formal education imparted to farmers where field oriented, discovery based learning is created. It is a participatory farmers' learning process characterized by season long training programme, aimed at imparting practical knowledge to farmers.

iii. Fruit tree farming. This is for food security and environmental conservation in order to bridge the gap between agriculture and forestry. The basic need of the farmers is food, and hence the most practical way to convince them to commit their scarce land resources to tree farming is through agroforestry. Fruit trees such as grafted mangoes and oranges are fast growing in these areas, are a source of food and income, and provide environmental and ecological benefits.

iv. Regular monitoring and evaluation. This is important for determining the performance of the different forestry technologies adopted by farmers. Farmers suggested that KEFRI should make regular follow ups on demonstration plots, nurseries and trained groups. Regular monitoring and evaluation also maintains a close working relationship with the community and ensures a sustainable approach to disseminating forestry technologies.

v. Ensuring a strong linkage with local leaders and extension workers.

Community participation is the cornerstone of community forestry

Local leaders in rural areas are key decision and policy makers. Involvement of these leaders in mobilization and dissemination activities will have more impact on the community at large. A successful forestry initiative creates additional opportunities for all community members to participate in decision making. Table 2 is a summary of the suggested ways of improving forestry technology dissemination in the Kilifi and Kwale Counties.

Table 2. Suggested ways of improving technology dissemination

Suggested ways of improving technology dissemination	**Kwale and Kilifi Counties**
Increasing the number of demonstration plots and field days	42 %
Formation of farmer groups or farmer field schools	27 %
Promoting agroforestry tree species and fruit trees	16 %
Regular monitoring and field visits	10 %
Strong linkage with local community leaders	5 %

Technology Dissemination Methods used by other organizations in the two counties

There are different organizations (Government, NGOs, CBOs etc.) that provide extension services and trainings to farmers in the two counties. These organizations use various means to disseminate technologies which include:

i. Demonstration plots through woodlots establishment such as KOMAZA in Kilifi County
ii. Farmer groups and field schools by the State Department of Agriculture in extension services
iii. Community training through workshops and seminars by various NGO’s
iv. Cash for asset incentive mechanism for on-farm soil and water conservation technologies by the World Vision.

Conclusion and Recommendations

The rate of adoption of forestry technologies is low in Kwale and Kilifi counties; hence there is need for more extension services, focusing mainly on agroforestry tree species, which would enhance adoption of forestry technologies. Furthermore, the study area has a high potential for fruit farming. Hence Kenya Forestry Research Institute should focus on fruit and fodder tree species on farms in order to reach a large number of farmers to adopt tree farming technologies. Demonstration plots and community sensitization fora can play an important role in disseminating forestry technologies.

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Application and Impact of Knowledge and Skills Acquired from Participatory Natural Resources Management Training in Kenya

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Abstract

Kenya Forestry Research Institute (KEFRI) developed a training programme entitled 'Participatory Natural Resources Management Course' in 2010. The Course aimed at enhancing knowledge and identifying opportunities for sustainable participatory natural resource management, as well as improving skills to implement relevant activities. Two hundred and ninety one (291) participants from 30 different organizations in Kenya were trained between 2010 and 2016. A survey was undertaken to assess how the knowledge and skills acquired during the training programme were applied and their impact. A structured questionnaire was administered to 105 randomly selected course ex-participants. The results indicated that various skills were acquired from the training with the highest rating being on soil and water conservation (11.1 %). Knowledge and skills acquired were as mainly applied to advice or train farmers (35.5 %), while 32.9 % used the knowledge to facilitate technical training of relevant officers. The most commonly used methods to build capacity of communities were group training rated at 31 %, and field days at 27 %. These methods were reported to be cost effective and ensured coverage of many farmers. Most ex-participants commonly promoted technologies learnt which included: tree nursery and woodlot development; boundary tree planting; soil conservation; forest, woodland and hilltop rehabilitation, and fruit tree production. Ex-participants in collaboration with the communities had introduced and designed various innovative technologies and approaches such as: climate change adaptation and mitigation measures; food security initiatives, gender empowerment processes, and income generation to ensure sustainability of natural resources. The training was used in building capacity of natural resource managers. There is need to continue supporting the training programme in order to have a critical mass of trained personnel.

Keywords: Impact, assessment, ex-participants, natural resources, sustainability, participatory

Introduction

Increase in population, rapid economic growth, and over-exploitation of forests and woodlands have continued to put pressure on existing natural resources. This pressure has resulted in environmental degradation, compromising the ability of natural resources to provide renewable resources including food, water and wood especially for biomass energy. Some of the strategies that have been identified for reversing environmental degradation include development, promotion and adoption of technologies and practices that ensure sustainable management, conservation and utilization of natural resources (MENR, 2016, Bojo *et al*., 2000).

To achieve environmental sustainability, it is increasingly being recognized that different stakeholders including communities using or living adjacent to key natural resources, need to be actively involved in activities related to natural resources management (GoK, 2010), especially through participatory approaches. Application of participatory approaches to environmental management has increased, as it is a paradigm shift from the traditional top-down which are, centralized, exclusionary approaches to natural resources management (Kumasi *et al*., 2010, Kapoor, 2001, Hulme and Murphree, 1999).

Emerging challenges such as climate change and extensive land degradation require participation of various stakeholders to address. These challenges have also contributed for need to apply participatory approaches to Natural Resources Management (NRM). Van Crowder *et al*., (1998) noted that to effectively contribute to agricultural and natural resource productivity, changes and adaptation in agricultural education and training are required. Participatory Natural Resource Management (PNRM) is one such approach that has been recognized as a new training strategy for its ability to build trust by communities (Dungumaro and Madulu, 2003), alleviate social conflicts and protect public interest. Participation also enables communities to gain practical experiences through hands-on activities, and to be involved in planning, analysis and decision-making of their natural resources (CANARI, 2011; KFS, FAO, JICA, 2011; Probst and Hagmann, 2003).

Kenya Forestry Research Institute (KEFRI) whose mandate is to: undertake research in forestry and allied natural resources and to disseminate research findings to stakeholders including those involved in natural resources utilization and management, has continued to build capacity of stakeholders through various approaches including tailor-made training (KEFRI, 2013). In the past, KEFRI targeted information transfer mainly to Kenya Forest Service (KFS), which was perceived as the main dissemination agent in forestry. However, due to realization of a need for multidisciplinary approach to NRM, KEFRI initiated a training programme in 2010 entitled; Participatory Natural Resources Management Course (PNRMC), to build capacity of a wide range of natural resources managers. The training programme was also informed by a need to empower natural resources managers to draw lessons from past and on-going efforts to effectively scale-up proven technologies and consequently empower local communities to actively participate in NRM (Mukolwe *et al*., 2016).

The training aimed at building capacity of individuals in target organizations with knowledge and skills in natural resource management. However, the value of a training programme can only be gauged on the worth of the impact resulting from transfer of knowledge from training to the work performance in the participating organization through application and adoption of skills acquired. The effectiveness of a training programme and whether the programme offered appropriate solution for identified training needs and; to inform subsequent trainings can only be gauged through an impact assessment survey. A post-training evaluation of the PNRM course was therefore undertaken with the objective of assessing how knowledge and skills acquired during the training were being applied and changes that may have resulted from their use.

Methods

Data Collection

Data were collected through a survey by administering a structured questionnaire to ex-participants who had attended the Participatory Natural Resource Management Course (PNRMC) at KEFRI between 2010 and 2016. Ex-participants were drawn from 30 different institutions. A total of 166 out the 291 ex-participants were selected. The ex-participants were purposefully selected from various years and across the various institutions, which included; Government departments, learning institutions, commercial institutions, parastatals, Non-governmental Organizations (NGOs), Community Based Organizations (CBOs), civil societies, and farmers. Selected ex-participants were contacted either through e-mail or by phone, and invited to take part in the survey. A structured questionnaire was developed, pre-tested and e-mailed to the identified respondents who were requested to respond within a period of two months between April and May 2016. A follow-up on survey response was done through email and phone calls. In addition, the questionnaire was administered through face-to-face interviews, mainly to the respondents who did not have access to emails. The face-to-face interviews also gave the evaluators an opportunity to observe activities being undertaken in cases where the respondents selected were farmers. A total of 105 of the 166 ex-participants targeted responded, giving a response rate of 63%.

The survey included questions on: relevance which was tailored to the mandate of the organizations, major knowledge and skills acquired during the training and how they were applied; reference to training material issued; effectiveness which was reviewed through enumeration of the natural resource management activities promoted or used, involvement with farmer groups, implementation of action plan developed during the training, and transfer of knowledge to others; impact and innovative approaches introduced or designed to ensure sustainable PNRM, and factors that may promote or hinder sustainability of PNRM activities.

Data including usefulness of knowledge and skills acquired were measured on a three-point frequency scale that included; very useful, useful and not useful. Although many questions were close-ended, the survey also included open-ended questions where respondents were invited to enumerate other items such as: climate change challenges encountered as well as mitigation and adaptation measures adopted by communities; innovative approaches communities have introduced or designed to ensure sustainable PNRM; and challenges encountered while working with communities. Change stories where ex-participants included explanations on activities undertaken, especially those linked to innovations were also recorded. Open-ended questions responses were grouped into similar sets, after which qualitative analysis was undertaken.

Data entry and analysis

The collected data was coded and entered in MS Excel. Data cleaning, collating and analysis were done using MS Excel programme and SPSS. Descriptive statistics using frequencies was carried out to show general trends in the various variables under investigation. Since the survey assessed individual opinions, analysis on group categories was not undertaken.

Results and Discussion

Relevance of the training programme

Ex-participants were drawn from organizations whose mandates were on environmental conservation. About 23.5 % of the organizations had mandate related to sustainable production and consumption systems, while maintaining natural resources (Table 1). Other institutional mandates were related to environment conservation, food security and livelihood improvement emphasizing high relevance of the training on PNRM. Selecting participants involved in relevant field has been reported to be appropriate as this ensures immediate application of knowledge and skills acquired by participants (Wanjiku *et al.*, 2016). Such selection criteria is in agreement with that proposed by UNEP (2009) which emphasized the need for a training course to focus on requirements for a well-targeted group to ensure effective training and application of knowledge for impact.

Table 1. Mandates of ex-participant organizations

Mandate	% frequency
Sustainable production and consumption system while maintaining natural resources	23.5
Plan, co-ordinate and implement development programmes	14.7
Environment conservation	14.7
Management development and conservation of forestry resources	14.7
Promotion of sustainable agriculture and rural development through practical, training and education	8.8
Enhancing food security and healthy education standards	5.9
Facilitating provision of clean, sustainable, reliable and secure energy services	5.9
Nursery and tree production	5.9
Environment management, community empowerment and livelihood improvement through tree planting	5.9
Total	**100.0**

Main skills and knowledge acquired from the training

The ex-participants indicated that the major knowledge and skills acquired from the PNRM training included; soil and water conservation (11.1%) and natural resource management and utilization (8.9 %). Development of work plans; tree seed selection and production; and participation of the community had a frequency rating of 6.7 % each. All ex-participants had applied knowledge and skills acquired, which implies that the training was relevant. Much of the knowledge and skills acquired was applied to advice and train farmers (35.5 %), facilitate training (32.9 %) and develop action plans (23.7 %). The ex-participants acted as facilitators in training of trainers and 40,416 other stakeholders benefited from the knowledge and skills acquired during the training.

Use of training materials issued

The training materials issued during the training were also highly relevant as 97 % of the participants had referred to them. The training materials mostly referred to are outlined in

Table 2. The materials were mostly used, and were relevant for; community mobilization and sensitization meetings (8.9 %), soil and water conservation and project work (8.9 %), development of work plans and writing proposals (8.9 %) and tree nursery management (7.1 %).

Table 2. Training materials mostly referred to by ex-participants after the Participatory Natural Resources Management training

Field of reference material	% frequency
Soil and water conservation	11.3
Action and project plan development	7.0
Bamboo propagation	5.6
Farmer Field School (FFS)	4.2
Nursery management guideline	4.2
Climate change causes and impacts	4.2
Sustainable natural resources management through best farming practices	4.2

Effectiveness of the training programme

The level of promotion and use of technologies and practices varied from 39.4 % to 83.3 % with tree nursery activities being the most commonly promoted followed by woodlot development on-farm, while conservation of woodlands, hilltops and forests was the least promoted (Table 3). Technologies and practices that were occasionally or not promoted or used could be attributed to the fact that the respective organization did not have the specified activity within their work plan.

Table 3. Natural resource technologies and practices and their level of promotion and use

	Level of promotion and use (% frequency on rating)			**Total (%)**
Natural resources technologies and practices	**Commonly promoted/used**	**Occasionally promoted/used**	**Not promoted /used**	
Tree nursery activities	83.3	16.7	0.0	100.0
Woodlot development on-farm	74.3	11.4	14.3	100.0
Soil conservation	65.7	28.6	5.7	100.0
Fruit tree production	62.5	27.5	10.0	100.0
Trees on boundary	61.8	32.4	5.9	100.0
Water resource management	59.4	34.4	6.3	100.0
Planting trees in degraded forests, woodlands and hilltops for rehabilitation	58.8	26.5	14.7	100.0
Fodder trees and shrubs	54.3	34.3	11.4	100.0
Beekeeping	45.5	27.3	27.3	100.0
Conservation of woodlands, hilltops and forests	39.4	33.3	27.3	100.0

Usefulness of knowledge and skills acquired from the training

About 86 % of the ex-participants indicated that knowledge and skills acquired during the training was very useful, compared to 14 % who stated that it was useful. The main reasons for the rating on usefulness of the knowledge and skills acquired during the training are as outlined in Table 4. The highest rating (30.6 %) was for acquiring knowledge to advice farmers while the next highest rating (11.1 %) was for natural resource management. The high rating on usefulness of knowledge and skills can be attributed to the fact that the training was developed after undertaking a Training and Technology Needs Assessment which highlighted training gaps in the institutions where participants had been drawn from.

Table 4. Reasons for rating knowledge and skills acquired during the Participatory Natural Resources Management training as useful

Reason	% frequency
Acquire knowledge to advice the farmers	30.6
Natural resource management	11.1
Service delivery and performance	8.3
Enhancing community livelihood	5.6
Friendly income generating activities	5.6
Environmental sustainability and conservation	5.6

Involvement in farmer groups practicing natural resource management activities

About 81 % of the participants were involved in farmer groups practicing NRM activities. Different ex-participants were involved in different groups which included; Community Forest Associations (CFAs) (15.1 %), Water User Associations (WUAs) (9.6 %), Community Wildlife Association (CWAs) (9.6 %), Charcoal Producers Association (CPAs) (9.6 %), and farmer groups (9.6 %). Various information dissemination methods were used for training the farmers groups, with the most commonly used method being group training (31 %), followed by field days (27 %) as shown in Figure 1.

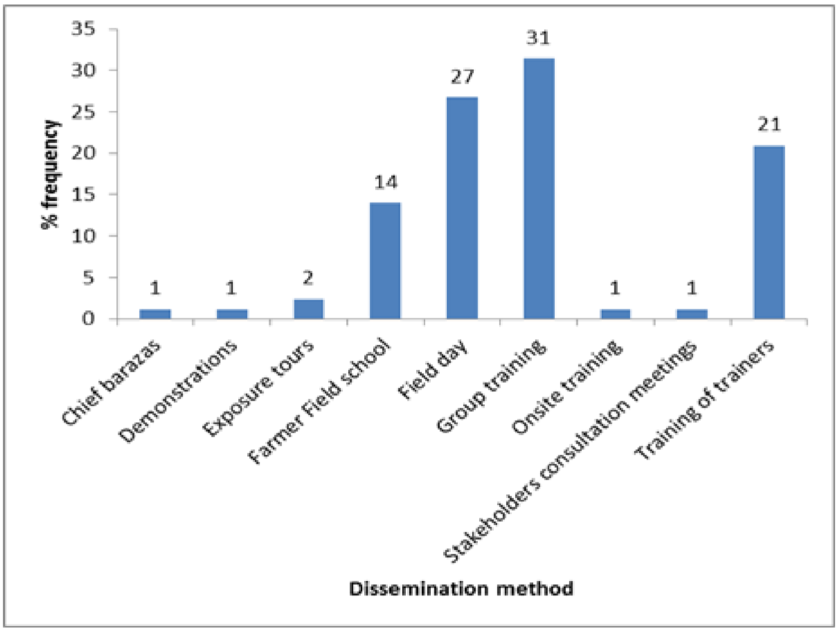

Figure 1. Information dissemination methods commonly used for group training by ex-participants of the Participatory Natural Resources Management training

These information dissemination methods were preferred as they; enabled large coverage of stakeholders, attracted positive response from the community, and were cost effective. However, some challenges mainly attributed to lack of resources and low literacy level was experienced in implementing community group activities.

Action plan implementation

Most of the ex-participants (85 %) had prepared individual action plan during or immediately after attending the PNRMC. About 56 % of the ex-participants indicated that they had an opportunity to implement their action plan. Those who did not implement the action plans cited lack of human and financial resources as the main hindrance. Mukolwe *et al.* (2016) reported that for action plans to have a high level of implementation, it should be aligned to an organizations' mandate and work plans, and should be discussed with supervisors in order to attract funding from within the institutions.

Transfer of skills and knowledge gained to other stakeholders

The survey indicated that ex-participants had transferred skills and knowledge acquired from the training to about 40,416 stakeholders that included farmers and colleagues. The different stakeholders have since received and utilized the knowledge and skills transferred to them by ex-participants (Table 5). Adoption of the promoted practices by beneficiaries can be attributed to the fact that their application improved the user's socio-economic status, land productivity and environmental conservation. Hiebert (1974), reported that the probability of adoption increases as the information pertaining to production increases through extension and farmer training efforts.

Table 5. Utilization of skills and knowledge by beneficiaries

Knowledge or skills	% frequency
Establishment of tree nursery	19.0
Tree planting	16.7
Soil and water conservation	11.9
Conservation of tree cover	7.1
Bamboo propagation	4.8
Development of action plan	4.8
Formation of sustainable groups	4.8

Climate change issues

A high number of ex-participants (94 %) indicated that the communities they worked with were aware of natural resource challenges and problems brought about by climate change. Communities practiced various measures to address the identified challenges as shown in Table 6. Tree planting, afforestation and reforestation were identified as a major climate change adaption and mitigation measures for many challenges identified including: biodiversity loss and desertification; forest and land degradation; and flooding and drying of water sources. This is in line with Sustainable Development Goal (SDG) 15 which calls for the need to; Protect, Restore and Promote Sustainable Use of Terrestrial Ecosystems, Sustainably Manage Forests, Combat Desertification, and Halt and Reverse Land Degradation and Halt Biodiversity Loss.

Table 6. Climate change challenges and mitigation or adaptation measures by communities

Climate change challenge	Mitigation or adaptation measure
Biodiversity loss and desertification	Tree planting/afforestation/reforestation
Food insecurity	Planting drought resistant crops
	Early land preparation and growing of fast growing crops
	Livestock feed preservation
	Irrigation and mulching
Forest and land degradation	Tree planting, afforestation or reforestation
	Establishment of woodlots
Extinction of indigenous species	Protection of water sources
	Domestication of indigenous species
Pests and diseases	Use of Integrated Pest Management (IPM)
	Avoiding excessive use of pesticides
	Early land preparation and growing of fast growing crops
	Working with stakeholders to equip farmers on pest and diseases management
Drought	Plant drought resistant crops
	Application of new farming techniques such as smart farming
	Water harvesting techniques
	Irrigation and mulching
Drying of water sources	Protection of water catchment areas and sources
	Tree planting, afforestation or reforestation
Floods	Conservation of riparian areas
	Controlling soil erosion
	Tree planting, afforestation and reforestation
Poverty	Alternative source of income
	Application of new farming techniques
Reduced crops and livestock yields	Early land preparation and growing of fast growing crops
	Efficient harvesting and utilization of rain water
	Feed preservation for livestock
Unpredictable weather patterns	Grow drought resistant crops
	Early land preparation and growing of fast growing crops
	Protection of water sources
	Selling livestock before animals start to die
	Insurance for animals
	Tree planting, afforestation and reforestation

Innovative approaches to ensure sustainable PNRM

The survey showed that ex-participants and communities they worked with had introduced and designed various innovative approaches to ensure sustainability of PNRM (Table 7). These innovations had benefits towards; climate change adaptation and mitigation, food security, gender empowerment, alternative household income, livestock improvement, NRM and conservation activities.

Table 7. Innovative approaches for sustainable management of natural resources designed by ex-participants of Participatory Natural Resources Management training and communities

Benefits	Innovative approaches
Climate change adaptation and mitigation	Introduction of agroforestry technologies
	Capacity building on value addition of fruit farming
	Climate smart agriculture
	Energy saving technologies
	Organic farming
	Water harvesting and management techniques
	Diversification of crops and livestock
	Educating farmers on new techniques
	Planting fast growing crops
	Integrated farming
	Irrigation
	Planting indigenous food crops
	Soil conservation
	Planting different species of trees and shrubs
Household income	Income generating Activities (IGAs) such as bee keeping, fish farming, poultry farming)
	Capacity building on value addition of fruit farming
	Formation of conservation and environmental groups for women and youth
	Diversification of crops and livestock
	Educating farmers on new techniques
	Entrepreneurship and business group formation
Natural resource management and conservation	Application of agroforestry systems
	Use of climate smart agriculture
	Communal planned activities
	Formation of conservation and environmental groups for women
	Education on endangered tree and plant species
	Use of energy saving technologies

These innovative approaches can be linked to new knowledge and skills acquired during the training, as adoption of new tools has been reported to promote evolution of management practices (Gordon and Chadwick, 2007). Such evolution consequently makes organizations perform more effectively, allows for creation of new inventions and promotion of adoption of technologies to local conditions. Thus the PNRM has enhanced capacity of the ex-participants to be able to solve environmental challenges.

Main constraints encountered in promotion and adoption of PNRM

The ex-participants encountered various constraints while promoting PNRM practices as shown in Table 8. However, the ex-participants have come up with innovative strategies to overcome the challenges. These innovations include; working with the limited available resources, attending other relevant trainings to acquire new information and skills such as value addition and how to effectively train farmers.

Table 8. Main constraints encountered by ex-participants

PNRM aspect	Constraint
Government policies	Contradicting government policies and legislations
Information and resources	Few resource centers
	Inadequate human and financial resources
	Low literacy level of communities hindering them from accessing new technologies
	Inappropriate land use
Labour	High cost of skilled labour
Land size	High population per unit area
	Insecure land tenure
	Small farm size
Markets and marketing information	Inability to predict seasonal trends of products
	Lack of markets
	Presence of middlemen
Technologies	Expensive technological facilities such as greenhouses
	Low adoption rate of technologies by farmers
	Low literacy level to access new technologies
	Slow uptake of technologies

Conclusion and Recommendations

The survey established that PNRM course is relevant as all ex-participants applied the knowledge to advice or train farmers. The PNRM course acted as a training-of-trainers, after which a considerable number of stakeholders continue to be empowered to promote, as well as use innovative technologies and practices in NRM. The survey identified low literacy levels and lack of resources and relevant information as key areas hindering adoption and promotion of PNRM. There is need to address these constraints through policy direction and for KEFRI to continue with the implementation of the training programme in order to build a critical mass of trainers who can promote adoption of NRM practices.

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Adoption of Forestry/Agroforestry Technologies in the Drylands of Kenya: A Case Study of SOFEM, ARIDSAK and ISFP Extension Models

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Abstract
The reconnaissance survey was undertaken in Kitui and Makueni counties where the Social Forestry Extension Model Development Project (SOFEM), Intensified Social Forestry Project (ISFP) and Agroforestry for Integrated Development in Semi-Arid Areas of Kenya (ARIDSAK) projects were implemented. The purpose was to identifying the socio-economic factors influencing adoption of forestry technologies. Data was collected using a semi-structured questionnaire administered to a total of 324 farmers who were randomly selected from both counties. Key informants from Kenya Forest Service and the departments of Agriculture in all the sites were also interviewed using a checklist. The data was analyzed using SPSS version 21 and Excel computer software programs, and subjected to descriptive statistics involving computation of frequency, means and percentages. Results were presented in graphs and tables. The results of the study indicated that, the drivers of adoption of forestry/agroforestry technologies across the study sites include boundary conflicts (50.2 %), fuel wood shortages (24.8%) and strong winds (5 %). Other drivers were diversification of income sources (5 %), high temperatures (10 %) and timber shortage (5 %). The sources of forestry/agroforestry technologies information and technical backstopping were reported to be from Kenya Forestry Research Institute (50 %), Ministry of Agriculture (20 %), Kenya Forest Service (15 %) and local NGOs (10 %). Other sources of information (5 %) include chiefs' barazas, local radio stations, newspapers and farmer exchange programs. Forestry/agroforestry is a means of increasing food production and wood availability, hence playing a vital role in poverty alleviation and improvement of living standards in drylands.

Key words: Social Forestry, Technology, Adoption, Drivers, information dissemination

Introduction
The Arid and Semi-arid Lands (ASALs) of Kenya are characterized by numerous woods/bushes. Historically, rural populations in these areas never had to plant trees, as they were able to obtain them from the natural woodlands. The ASALs, however, are particularly coming under intense pressure due to population growth, expansion of agriculture and pasture, and development of infrastructure. The demand for natural resources is recognized as one of the major driving forces of reducing wood biomass in these areas. High levels of poverty are known to be a driving force exerting pressure on the dryland natural resources.

This situation in drylands has gained attention from various sectors of the nation which are working with the affected communities to reverse the situation.

The vast majority of the communities in the ASALs are now engaging in forestry/agroforestry activities with efforts being geared towards increasing land productivity, energy use efficiency and, ultimately household income. Besides, forestry/agroforestry also offers a number of service functions such as soil erosion control, and maintenance and improvement of soil fertility (Young, 1997). Other service functions include reduction of wind speed, weed control and provision of live fencing. Adoption of agro-forestry technologies in ASALs has the potential to halt land degradation and improve soil fertility. When trees are properly managed and integrated into farming systems, they improve agricultural productivity and maintain environmental integrity. Several forestry/agroforestry technologies have been tested in the drylands through extension models which mostly focus on solving technical problems, such as providing tree nursery management skills, introducing new tree species, or technology such as improved cooking stoves.

In Kenya, Forestry/Agroforestry has received much attention in recent development efforts in the drylands. This has been reflected in numerous projects that were aimed at supporting tree-growing efforts and other farm-based activities of the communities. Several ministries notably Ministry of Environment and Forestry (ME&F) and other government extension agencies (Tengnas B., 1994) made efforts to promote the adoption of forestry/agroforestry technologies by farmers. The efforts were piloted in different regions across the drylands of Kenya including Kitui and Makueni. In the past 10 years, Kenya Forestry Research Institute (KEFRI) in collaboration the Government of Belgium and Japan international Cooperation Agency (JICA) initiated various forestry/agroforestry projects to ameliorate degradation and increase tree cover in the drylands through on-farm tree growing and other farm-based activities using selected extension models. Hence, adoption of forestry/agroforestry technologies was successfully undertaken through Social Forestry Training Project (SFTP), Social Forestry Extension Model Development Project (SOFEM), Social Forestry Project in semi-arid areas of Kenya (ISFP) and Agroforestry for Integrated Development in Semi-Arid Areas of Kenya (ARIDSAK).

The SFTP was implemented between 1985 and 1997 with a focus to develop tree nurseries and planting technologies for the ASALs and to train stakeholders on social forestry. SOFEM Project was implemented from 1997 to 2001 and aimed at developing an extension model in promoting the establishment of farm-forestry amongst communities in the ASAL regions of Kenya. The project was succeeded by ISFP in semi-arid areas of Kenya in 2004 until 2009 which was aimed at consolidating past efforts in social forestry development and enhancing the capacity of farmers/farmer groups, Kenya Forestry Service (KFS) and other stakeholders to promote farm forestry in ASALs.

ARIDSAK was a bilateral project implemented in Makueni and Kajiado Counties and funded by the governments of Kenya and Belgium. The project used a research and development approach on-station where technologies were developed and tested by specialists. Promising technologies were further verified under farmers' conditions. Proven technologies were then packaged in the form of extension materials for use by extension staff and farmers within the project areas. Through this approach, neighbouring farmers were expected to benefit through learning experiences of democratically elected farmers.

Elsewhere in many parts of the world, despite technological advances, forestry extension has experienced uneven success due to inadequate adoption rates or abandonment of the technologies (Subhrendu *et al*., 2003). However, adoption and dissemination of forestry/agroforestry technologies is complex due to a number of reasons including uncertainty, cost and benefits of the technology, gender, social capital, socio-cultural practices, high costs of labor, access to markets, and credit among others (Phiri, 2004, Rao *et al*., 2010, Nordin *et al.,* 2014,). However, there are socio-economic and biophysical factors that influence the adoption of the forestry/agroforestry technologies. Socio- economic factors such as education level, income, farm size and family size influence greatly the adoption rates of forestry/agroforestry across the communities (Onyango, 1993).

In this study, a reconnaissance survey was conducted in Kitui and Makueni Counties to assess the level of adoption of forestry/agroforestry technologies developed over the projects period under SOFEM, ISFP and ARIDSAK. The objectives of the study were to identify the socio-economic factors influencing adoption of forestry/agroforestry technologies, identify and assess the drivers of adoption and assess how adoption of the technologies varied by extension approach, technology characteristics and social setting. In addition, sources of information on forestry/agroforestry technologies would be identified, and recommendations on extension approaches applicable in different situations given.

Methodology

Study sites

The study was undertaken in Kitui and Makueni County in the Eastern region targeting the general population of core farmers, SOFEM and ARIDSAK trainees. Kitui County is located between latitudes 0°10' and 3°0' South and longitudes 37°50' and 39°0' East. It has a low lying topography with arid and semi-arid climate (Government of Kenya GoK, 2014). It covers an area of 30,496.4 km^2 including 6,369 km^2 occupied by Tsavo East National park. The county borders seven other counties: Machakos and Makueni to the west, Tana River to the east and south-east, Taita Taveta to the south, Embu to the north-west and Tharaka-Nithi and Meru to the north. The altitude of Kitui County ranges between 400 m and 1800 m above sea level. Temperatures are high throughout the year, ranging from 14 °C to 34 °C. The hot months are between September/October and January/February. The maximum mean annual temperature ranges between 26 °C and 34 °C whereas the minimum mean annual temperature ranges between 14 °C and 22 °C. July is the coldest month with temperatures falling to a low of 14 °C, while September is the hottest month with temperature rising to a high of 34 °C. Rainfall distribution is erratic and unreliable. The annual rainfall ranges between 250 mm and 1050 mm per annum with 40% reliability for the long rains and 66% reliability for the short rains. The population is at 1,147,200 people **(**Female: 602,002, Male: 545,195**)** (Kenya National Bureau of Statistics, 2009).

Makueni covers over 8,034.7 km^2 with a population of more than 900,000 people (Kenya National Bureau of Statistics, 2009). The County borders Kajiado County to the West, Taita Taveta to the South, Kitui to the East and Machakos to the North. It lies between Latitude 1^0 35´ and 3^0 00' South and Longitude $37^0$10´ and 38^0 30´ East (Government of Kenya, 2013). The terrain is low-lying from 600 m above sea level in Tsavo. The County is largely arid and semi-arid and usually prone to frequent droughts. The lower side which is very dry receives little rainfall ranging from 300 mm to 400 mm. The County experiences two rainy seasons, the long rains occurring in March/April, and the short rains occurring in November/December. The hilly parts of Mbooni and Kilungu receive 800 mm – 1200 mm of rainfall per year (GoK, 2013). High temperatures of 35.8 ^{0}C are experienced in the low-lying areas causing high evaporation that worsens the dry conditions.

Data collection and Analysis

A reconnaissance survey was conducted in Kitui County (Mutomo, Ikutha and Mutitu) and Makueni County (Kibwezi and Kathonzweni) to assess the impact and level of adoption of forestry/agroforestry technologies. Primary data was collected using a semi-structured questionnaire designed to gather information on socio-economic characteristic, wealth status, livelihood sources, social capital, forestry/agroforestry technologies and nursery establishment and management. Secondary was done through literature review from related and similar studies. The target population comprised of the core farmers, trainees of the three models (SOFEM, ARIDISAK and ISFP) and general farmers. The questionnaire was administered to a total of 324 farmers (Table 1) who were randomly selected from both counties. Key informants from Kenya Forest Service and the departments of Agricultural in all the sites were also interviewed using a checklist. Other issues assessed included dissemination activities, sources of information, benefits and future plans. Data obtained was analyzed using SPSS version 21 and Excel computer software programs. It was then summarized and computation of frequency, means and percentages done.

Table 1. Number of farmers interviewed in the study sites

Extension Model	Categories of Farmers	No. of Farmers Interviewed In 2010/2011	No. of Farmers Interviewed In 2011/2012
SOFEM	Core farmers	21	15
	Trainees	21	15
	General population	21	15
ISFP	FFS Graduates	30	6
	Trainees	25	11
	General Population	23	13
ARIDSAK	Democratic farmers	24	12
	Trainees	24	12
	General population	24	12
Total		213	111
			324

Results and Discussion

Socio-economic Characteristics of the stakeholders

There were 53 % male and 47 % female respondents across the extension models (SOFEM, ARIDSAK and ISFP) model. This shows that both genders play an important role in adoption of forestry/agroforestry technologies. However, men are the decision makers when it comes to implementation of the technologies and played an active role in the implementation of the projects and consequently in the study across the study sites. The higher response in male in the study greatly contributed to the adoption of forestry / agroforestry technologies positively. The age of the respondents was 30 -39 (40 %), 40-49 (23%), 50- 59 (20%) and over 60 years (17%) respectively. It was reported that 45% of the respondents had been 4-6 years and 55% had been 6-8 years in the project across the study sites. Education level of a farmer is believed to create favorable mental atmosphere for acceptance of new technologies that seem to benefit (Wafuke, 2012) hence, in this study education was a key determinant. Adekunle (2009) pointed out that the level of education of farmers will directly affect their ability to adapt to change and to accept new ideas. A higher percentage of the respondents were married (90%), while 7% and 3 % were widowed and single respectively. Majority (43%) of the respondents held 1-5 acres of land, 27% (5-10 acres), 12% (10-15acres), 10% (15-20 acres), 8% (above 20 acres) respectively. Land is one of the factors required in production. Therefore, the availability of adequate land in the study sites would contribute to the adoption or lack thereof of forestry/agroforestry technologies (Table 2).

Table 2. Socio-economic characteristics

Variable	%
Gender	
Male	53
Female	47
Age	
30-39	40
40-49	23
50-59	20
over 60	17
Education Level	
4-6 Years	45
6- 8 Years	65
Land size (acres)	
1-5 acres	43
5-10 acres	27
10-15 acres	12
15-20 acres	10
Above 20 acres	8
Marital status	
Married	90
Widowed	7
Single	3

According to Amaza and Tashikalma (2003), the literacy level of farmers is important as it determines the rate of adoption of improved technology for increased productivity. In this case, it may have accelerated the adoption of forestry/agroforestry technologies due to the enhanced ability to acquire technical knowledge across the study sites. Besides, farmers who have some level of education respond readily to improved technology than those with no formal education.

Forestry/agroforestry technologies practiced

A higher percentage (78 %) of the respondents in all the study sites adopted various forestry/agroforestry technologies on their farms. The technologies adopted were shade (15.3%), windbreak (5 %), tree boundary (40.1 %), home garden/fruits (8 %), fuelwood (30.1%) and timber/poles (2.6 %). Various tree species were used for different technologies such as *Melia volkensii*, *Senna siamea*, *Grevillea robusta* and *Mangifera indica*. Lionberger explained that farmers prefer different forestry/agroforestry technologies based on farm size and the direct benefits to their well-being. Therefore, most farmers adopted tree boundary technology because of the vast benefits would be obtained (Table 3). The most common drivers of adoption of forestry/agroforestry technologies across the study sites boundary conflicts (50.2 %), fuel wood shortages (24.8 %) and strong winds (5 %). Other drivers were to diversify income sources (5 %), high temperatures (10 %) and timber shortage (5 %)

Table 3. Trees species adopted by farmers

Tree species	**Frequency**	**Percent**
Melia volkensii	29	30
Senna siamea	12	24
Mangifera indica.	11	20
Azadirachta indica	10	5.0
Grevillea robusta	13	13
Total	**72**	**100.0**

Planting Material sources

There was an active involvement in planting materials/seeds collection across the study sites for implementation of the forestry/agroforestry technologies. Planting materials/seeds were obtained from various sources such as collecting from existing forests (51 %), purchase from local vendors (19 %) and on-farm collection (30 %). An active participation was seen in nursery establishment and management; 55 % of the respondents had own nurseries, while the rest (45 %) had none. A majority of those who owned nurseries had individual nurseries (75 %), while 25% were in nursery groups. The respondents raised planting materials/seedlings for sale and individual use; 65 % sold the planting materials/seedlings while 35 % raised them for personal use. The seedlings raised in the established nurseries were *Senna siamea*, *Grevillea robusta*, *Mangifera indica*, *Citrus spp* and *Melia volkensii*. Respondents produced more *Senna siamea* seedlings (40%) *Grevillea robusta* (30%), *Mangifera indica* (15%) and Citrus spp (10%). It was noted that *Melia volkensii* (5%) seedlings production was very low in all the nurseries compared to other species because of the technicalities that are associated with its extraction, storage, and sowing. However, the respondents across the sites reported to have experienced various challenges during the implementation of such activities. The stated challenges included water shortages, prolonged dry periods, pests and disease attacks, inadequate potting materials and shortage of planting materials (Figure 1).

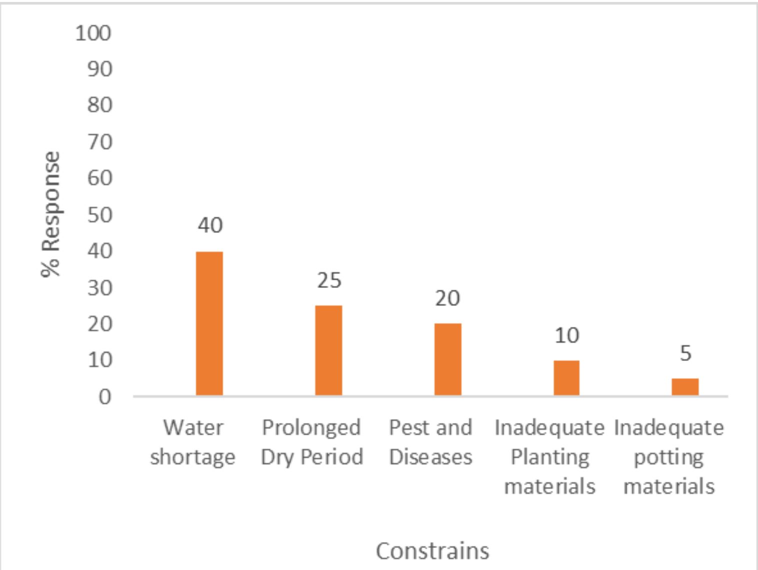

Figure 1. Contraints encountered by the stakeholders

Dissemination of forestry/agroforestry technologies

Dissemination of information is critical since it creates awareness on present issues. It enables stakeholders to be skilled and knowledgeable on developed technologies and best practices on their implementation. There was an active involvement of the respondents in dissemination activities in all the sites. It was reported that 64% of the farmers were involved in dissemination of the forestry/agroforestry technologies through farmer-to-farmer approach. The dissemination platforms were trainings, group meetings/chiefs barazas, field days, farmer visits and demonstration plots. The most common dissemination platforms used (Figure 2) were trainings (35 %), farm visits (30 %), field days (20 %), group meetings (10 %) and demonstration plots (5 %). Various forestry/agroforestry technologies disseminated included nursery techniques (31 %), grafting and budding (14 %), tree planting techniques (48 %) and horticulture (7 %). Additionally, 70 % of the farmers were reported to have made follow-ups with the trainees to monitor progress after their training activities while 30 % did not undertake follow-ups. Sources of forestry/agroforestry technologies information and technical backstopping were reported to be from Kenya Forestry Research Institute (50 %), Ministry of Agriculture (20 %), Kenya Forest Service (15 %) and NGOs (10 %). Other sources of information (5 %) included chiefs' barazas, local radio stations, newspapers and farmer exchange programs.

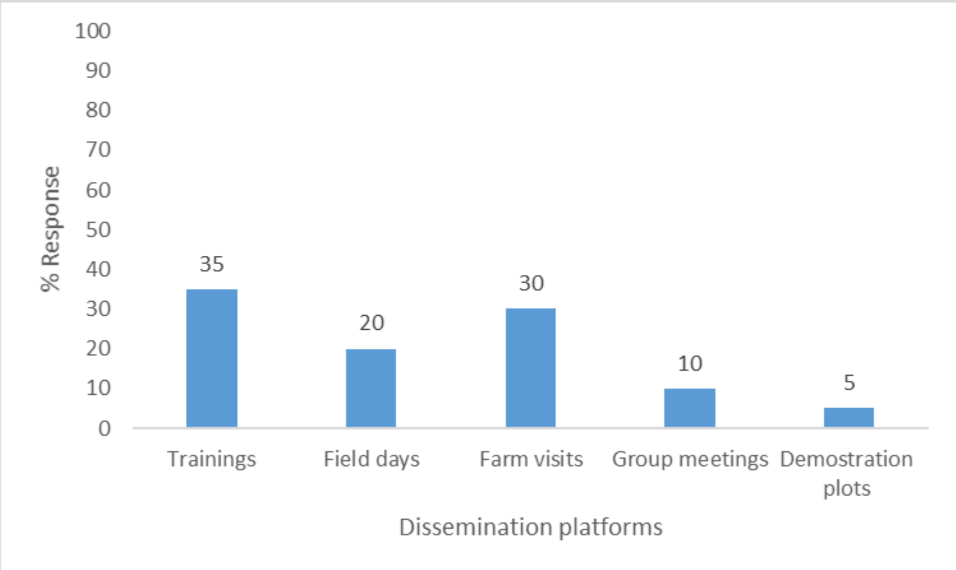

Figure 2. Dissemination platforms used by the stakeholders

Benefits of forestry/agroforestry technologies and future plans

The survey indicated that there were various benefits that accrued from the adoption of forestry/agroforestry technologies including on-farm tree planting, fruit tree farming, seedlings sales from the nursery and many others. The respondents used the forestry/agroforestry technologies domestically and commercially to improve their livelihood in various ways. The benefits were from poles, fruits and timber from various tree species such as *Grevillea robusta*, Eucalyptus spp, mango trees, among others. Farmers greatly benefited with fruits (42.9 %), fuel wood (25.1 %), reduced soil erosion (24 %) and other

benefits (8 %). The respondents earned an average profit of KES 1,480 (Eucalyptus), KES 31,962 (Mangoes), KES 2,216 (Pawpaw) and KES 72,886 (Oranges) that were sold per year.
Majority of the farmers (97 %) reported that they would expand forestry/agroforestry activities on their farms whereas 3 % had no plans. Majority of respondents planned to plant more trees (93.8 %), maintain the existing trees (3.1 %) and join groups that produced juices for sale (3.1 %).

Conclusion/Recommendations

Forestry/Agroforestry is a means of increasing food production and wood availability in drylands, hence playing a vital role in poverty alleviation and improvement of living standards among local dwellers. However, there is need to improve both formal and informal forestry/agroforestry education among rural communities for the technologies to widely be accepted. Farmers in these areas should be encouraged to practice forestry/agroforestry to benefit from increased crop yields and various tree products including fruits, wood, soil fertility construction materials, medicine and other unquantifiable benefits. Various platforms and strategies have been used to accelerate adoption of the forestry/agroforestry technologies though more technical support to beneficiary communities is required. Forming joint extension teams by the representative institutions that would lead to more efficient, synergetic agroforestry extension approaches would be a good strategy to accelerate the adoption of forestry/agroforestry technologies. Technical assistance is needed to facilitate the spread of forestry/agroforestry. Likewise, adequate information is required to keep farmers abreast with current trends and developments in the practice of forestry/agroforestry. Provision of economic incentives to farmers participating in agroforestry practices should be considered. However, to effectively improve dryland livelihoods, forestry/agroforestry should form part of an integrated rural development programme and thereby meet more of the farmers' basic needs than it presently does.

Acknowledgement

The authors would wish to thank the team that was involved in the survey for their tireless efforts. We are also grateful for the financial support from Kenya Forestry Research Institute.

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THEME 6: PARTNERSHIPS, NETWORKS AND RESOURCE MOBILIZATION

KEFRI feted with JICAs President award


Masaai Mara University Chancellor Prof. Mary Walingo and Dr. Ben Chikami exchanging an MoU

The Potential of Public Private Partnership (PPP) in Forest Sector Development in Eastern Africa

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Abstract

Kenya Forestry Research Institute and partners with support from African Forest Forum undertook a study 2016 to evaluate the potential roles of the private sector in development of primary and secondary forest production in 6 countries in Eastern Africa. The study revealed that primary forest production takes place in public natural forests, plantations, farm forests, community forests and private forests. The public sector agencies dominate ownership of indigenous and plantations forests but woodlands are largely owned by individuals and communities. The private sector that has entered into woodlots and plantation sectors development are largely driven by the high demand for forest products and good returns to investment. Instrument of land access in Uganda and Tanzania were leaseholds and permits. Privately owned wood based industries include saw mills, reconstituted wood, furniture making, transmission pole treatment plants, wood carving and charcoal production. The key products include sawn wood, fibre boards, particle boards, plywood, furniture, biomass energy, handcrafts and wooden poles among others. The non-timber products produced in the region include baobab fruits, tannins, tamarinds, gum arabic among others. The technical and management organization in primary production were mostly include tree growers' associations (TGAs) and few grower schemes supported by investment syndicates, companies, and wood based industries. Technical and commercial organizations in wood processing include saw millers, furniture and wood manufacturers associations. The countries have enacted policies and legislations with provisions to support private sector investment in the forest sector development. Most countries are net importers of various forest products mostly from Asia and Europe. Therefore, the region provides opportunities for private investors in primary and secondary forest production to meet the growing demand for forest products and enhance forest sector contribution to regions overall socio-economic development.

Introduction

Forests in Eastern Africa in terms of ownership fall into four categories public forests, community forests, farm forests and private forests. These forests for various reasons are experiencing heavy pressure from various factors that include high extraction rates, agricultural expansion and illegal logging among others. The combined outcome is loss of forest allied products and services through forest degradation and low productivity. Public sector forests are the main supplier of industrial and subsistence round wood timber in most countries but currently face management and governance related challenges. To enhance overall forest production most countries have implemented policy and legal reforms to attract farmers, communities and private sector into primary forest production and secondary processing and trade. The study targeted a wide range of players from large corporate firms, communities and individuals including women and youth. The study was aimed at identifying and understanding the interactions between different players with diverse interests in forest resources, derived benefits and challenges in managing and accessing forest resources in 6 countries of Eastern Africa namely Sudan, Uganda, Ethiopia, Kenya, Rwanda and Tanzania. The promotion of private sector participation in the forestry is premised on the expectation that such development will significantly impacts on employment creation, income generation and poverty alleviation. The public private partnership (PPP) is an emerging investment approach that has become popular in large infrastructure projects with potentials in forest sector projects. The study focus was on identification and promotion of viable PPP models that are compatible with sustainable livelihood development and contribute to the country's socioeconomic development.

Background and justification of the study

The purpose of the study was to facilitate development of an organized private sector in forestry development through identification and promotion of promising PPPs approaches in the forest sector that is all-inclusive, sustainable and contribute to livelihoods including gender considerations.

Objectives of the Study

The main objective of the study was to provide information to support the emergence of organized private sector in forestry through promotion of promising (PPP) approaches for sustainable forest management and enhanced livelihoods including gender considerations.

Study Methods

The study involved literature reviews of past works from various sources and some rapid reconnaissance surveys in key areas of the selected countries to facilitate updating of information and data especially in areas where gaps existed. The current paper relied on national reports from each of the participating countries.

Data analysis

The data and information were extracted from the national reports that were organized and those relevant to the synthesis were picked and used in various sections of the report. The key areas selected were the status and dynamics of primary and secondary forestry production, key investment areas, policies and legislations on public private sector partnerships, contribution of forest sector to economic growth and livelihoods and potential models of PPPs with promising future in the region.

Results

Actors in Forest Production

Actors in Primary Forest Production

The actors in primary forest production in the region range from individual producers, corporate producers and institutional producers. Smallholders produce operate mostly within an agricultural landscapes and constitute the largest primary forest producers that undertake different forms and scales of tree growing activities such as hedge trees, woodlots and agroforestry practices to produce saw logs, poles and wood fuel materials. The smallholder sector challenges include land, labour, capital, and technical knowledge. Due to these challenges most of the smallholder production is dominated by subsistence purposes but have diversified into short rotation commercial pole and saw log production within the last 10 years being attracted by high demand and good prices. The public agencies include government institutions mandated with managing the public forest estates and wildlife resources. These agencies are National Forest Authority (NFA) in Uganda, Kenya Forest Services (KFS) in Kenya, Tanzania Forest Services (TFS) in Tanzania, National Forest Corporation (NFC) in Sudan and Rwanda National Resources Authority (for forests) and Rwanda Development Board (for wildlife and protected areas) in Rwanda. The public forest agencies are mandated with the management of national forest reserves designated for production forests for the sustainable supply of forest products, nature reserves and other protected forests areas for biodiversity and water provisioning. The public agencies in many cases due various challenges such as inadequate funding, inadequate staffing and governance related issues have not been able to manage forests efficient for optimally production.

The private sector players include agricultural based enterprises such the tea estates that have diversified to tree growing for firewood production for curing tea and sawn wood for packaging tea with surplus being sold in local markets. Tea estates are dominant in tea growing areas in Kenya, Uganda, Rwanda and Tanzania. Other commercial tree growers include investment syndicates, companies and social entrepreneurs that have leased land from the government in Uganda and communities Tanzania. In Kenya they have entered into contracts agreement with farmers and local authorities to grow tree on sharing agreements or outright lease of the land for commercial tree growing for specified rotation period. The actors include New Forests Company, Green Resources, Global Woods, Better Globe Forestry and KOMAZA among others that have established plantations in hundreds of hectares mostly in Kenya, Uganda and Tanzania.

Forest Resources in Eastern Africa

Forest cover in Eastern Africa

In the region the main forest cover types are natural forests, woodlands and bushlands, and plantations and farms forests. The dominant forest cover types are woodlands and bushlands mostly located in the fragile dryland ecological zones of Sudan, Tanzania, Kenya and Uganda (Table1). The dryland forests also host pastoral communities that are changing to marginal agricultural activities. These forests product diverse products such as poles, firewood, charcoal non timber forest products (NTFPs), among others. The natural forest reserves are mostly owned by national governments and are some of the most biologically diverse and sometimes endemic and endangered species of flora and fauna. These forests are facing anthropogenic pressures from human needs that have led to fragmentation and overexploitation. Therefore, natural forests are likely to decrease in both land area and species diversity into the future. To counter such a process, many forest agencies have brought on board local communities and other interested parties into various forest co-management arrangements for enhanced livelihoods and long term sustainable management of forest resources in the region.

Farm forests are mostly trees grown within agricultural landscapes and constitute the largest primary forest producers practicing sustainable forest management in the region. Farm forests production objectives differ depending on scale and intensity with smallholder forests being subsistence in nature and medium more focused on commercial planting. The planting patterns also vary from hedge trees, woodlots and agroforestry practices to woodlots to produce sawlogs, poles and woodfuel materials. The farm forest sector challenges include inadequate land, capital, and technical knowledge hence dominance of subsistence purposes. However, the sector in the last 10 years has diversified into short rotation commercial pole and saw log production attracted by high demand and good prices.

The plantation forests form the smallest forest category that has been undergoing rapid expansion in the region for the last few decades. The forest plantation sector has been dominated by the public sector agencies in the past but due to governance and resource scarcity facing the exchequer has led to inadequate management that has lowered productivity and quality. The reduced production from public plantation has created timber deficits the selected countries that have translated into high timber prices that have attracted private sector players. The private players include tea estates, companies, syndicated investors, social entrepreneurs and small and large scale farmers. The private investors have employed various strategies that range from leasing land from government and private land owners to out grower profit sharing mechanisms. The forest sector players have established vast forest plantations in Kenya, Uganda and Tanzania has grown faster than public sector plantations within the last decade. The private sector investors deploy greater utilization models that include integrated utilization processing and value addition to minimize wastage in order to improve their operating profit margins.

The Public forest agencies in the region lack sufficient resources to adequately manage both natural and plantation forests and hence provide opportunities for some forms of public private partnerships to pool resources for sustainable management of forest resources. In Tanzania and Uganda private investors have established large swathes of commercial plantation forests that thrive on leveraging on efficiency in land use, efficient technologies and high demand for forest products. In Kenya private sector players are gearing for the potential opening up for forestland concessions under PPP process. The ranges of public forest investors include churches, schools, communities and state agencies such as prison, universities and wildlife services.

Table 1. Forest cover by types in Eastern Africa

Country	Woodlands (ha)	Natural forests (ha)	Plantation forests (ha)	Farm forests (ha)	Private forests (ha)
Kenya	26,560,000	1,220,000	107,000	10,385,000	90,000
Rwanda	240,000	125,000	74,644	-	11,737
Uganda	3,604,174	2,420,000	33,527	8,401,000	30,000
Sudan	11,731,000	1,345,000	6,121,000	-	6,332,000
Tanzania	48,702,000	250,000	554,500	20,000,000	44,220

NB: (–) in where no information was provided.

Plantation species preference

The countries in the region grow a wide range of exotic and indigenous species for both subsistence and commercial purposes. The species siting and mixes depend on many factors such as ecological attributes, land use history, land owners objectives among other factors. The Eastern African region has diverse climate condition ranging from wetter highlands to lowlands drylands where a variety of exotic and indigenous species can be grown. Kenya has the widest range of species mainly *Grevillea robusta*, *Eucalyptus grandis*, *E. saligna*, *E. camaldulensis*, *E. tereticornis*, various Eucalyptus hybrids, *Casuarina equisetifolia*, *Pinus patula*, *Cupresssus lusitanica*, *Acacia mearnsii* among hundreds of minor species of both indigenous and exotic species depending on the climatic and utility preferences among others values by both public and private investors.

In Uganda public and private commercial plantations are dominated by two exotic species for sawlogs, plywood and pole production purposes namely *Pinus caribaea and Eucalyptus grandis* but scattered pockets of *Pinus patula*, *P. oocarpa*, *Cupressus lusitanica*, *Araucaria spp.*, and Asiatic Teak *(Tectona grandis)* are also planted across the country. Some of the indigenous plantation species in the country include *Aningeria altissima*, *Antiaris toxicaria*, *Blighia unijugata*, *Maesopsis eminii*, *Markhamia lutea*, *Albizzia vcoriaria and Milicia excelesia.* In Rwanda the dominant exotic genus is Eucalyptus that occupy 59 % of planted area, others include *Pinus spp*, *Callitris*, Acacia spp**.**, *Cupressus* and *Grevillea spp.*, *Leucaena spp.*, *Calliandra calothyrsus*, *Alnus sp.* and *Sesbania sp.*

In Tanzania the commercial plantation are dominated by pines species that include *Pinus patula*, *P. elliottii* and *P. caribaea. Others include Cupressus lusitanica*, *E. saligna*,*E. maidenii* and *Tectona grandis*. Miombo woodlands and high natural forests are key sources for hardwood timber for local consumption and exports the following being the most common in the order of abundance *Diplorhynchus condylocarpon*, *Combretm zeyheri*, *Brachystegia spiciformis*, *Combretum molle*, *Julbernardia globiflora*, *Brachystegia boehmii*, *Dichrostachys cinerea*, *Pseudolachnostylismaprouneiolia*, *Combretum sp*, *Grewia sp*, *Grewia bicolor*, *Commiphora africana*, *Acacia sp*, *Commiphora sp*, *Markhamia obtusifolia*, *Uapaca kirkiana*, *Terminalia sericea*, *Brachystegia longifolia*, *Diplorhynchus mossambicensis and Dalbergia sp.* In Sudan the species managed for commercial production are mostly indigenous species mostly *Balanites aegyptiaca*, *Acacia seyal*, *Anogiessus leiocarpus*, *Albizia* *amara, Acacia senegal, Acacia tortilis, Ziziphus spinachristi, Khaya senegalensis, Acacia nilotica* and *Isoberlina doka* in the order of importance. Some few pockets of *Pinus patula* and *Cupresssus lusitanica* are located in high altitude forest reserves that are inaccessible due to insecurity. The rotational periods for planted trees range from 5 to 30 years depending on species, climatic conditions, end uses and market niche specifications. The shortest rotations observed are those for firewood and construction poles and the longest are for saw and peeler logs.

Forestry sector strength, weaknesses, opportunities and threats

Strengths

Most of the countries in the region have put in place favourable policies and laws, have pool of qualified technical personnel; have diverse actors including government, development partners and private investors; and growing demand for diverse forest product driven by rising population and urbanisation. The ready markets for diverse forest products and reasonable returns are the main attraction to small and large scale private investors into forest sector in the region.

Weaknesses

There is a high rate of forest cover loss in public and community forests due to competition from other land uses such as agriculture and settlements. The public sector owned forests are poorly managed due to inadequate supervision and protection. The sector is also experiencing inadequacy of legal provisions and technical skills. In most countries issues related to governance such as lack of transparency and accountability, flouting of policies and laws, insufficient participation of key stakeholders in decision-making processes, and poor coordination between enforcement and management agencies has made levels of compliance with forest-related policies and laws generally low. The forest production sector is generally characterized by inadequate guidelines, standards, and regulations particularly for private forestry. Many countries have not enacted the desired regulations to operationalize existing legislations that has made it difficult to effectively enforce even the existing laws.

The private sector investors face several challenges that include inadequate information on markets, limited access to credit, finance, capital and technology; and shortage of business and technical skills. In some countries there is general scarcity of good quality planting material due failure to establish and maintain good tree seed sources that has led to importation of seeds at high costs and in some cases poor quality plantation lead to huge losses when materials are rejected by buyers.

The official records on contribution of forests to the GDPs has remained low making forestry less competitive as compared to other land uses or investments because valuation tools have not captured adequately the non-marketed services of forests.

Forest sector operational in general is largely an informal sector therefore determining size, product stock and products flows is difficult making information on the sector minimal to guide development of appropriate interventions and policy decision making to improve the sector.

Private sector investors in some cases have faced hostile reception from local communities who seek compensation and in some cases resort to arson thus scaring away potential investors in plantation forests in community of national forest reserves.

Opportunities

There is a growing interest by the private sector on various forest based enterprises such as nursery operation, tree growing, processing and trade. Others include non-traditional products and services including ecotourism, carbon sequestration, water catchment services, and biodiversity products. Forest plantations for production of timber and poles offer attractive rates of return that compares very favourably with many other agricultural enterprises. There is also goodwill by governments and development partners to finance and provision of policy direction for forestry development. Some countries like Tanzania and Uganda has made available large tracts of land from the country's central forest reserves for leasing or concessions to private investors interested in development of forest plantations. The decision has been instrumental in attracting large of private investors' into turning around of degraded forests into productive use. The widening supply-demand gaps in many countries indicate that there will be ready market for timber, firewood and poles into the foreseeable future given increasing population and economy expansion at both national and regional levels. Kenya, Uganda, Rwanda and Tanzania are endowed with favourable climatic for fast growth of trees some attaining MAI of 75 m^3/ha/year making it among the global highest tree growth rates. The region have abundant skilled manpower trained in local premier forestry institutions at both diploma and degree levels that include Londiani Forestry college (Kenya), Nyabyeya Forestry College(Uganda), Lushoto Forestry College (Tanzania), Makerere University(Uganda), Sokoine University (Tanzania), University of Khartoum (Sudan) and Moi University (Kenya), among others.

Threats

The combination of population and economic growth do exert undue pressure on natural forest resources due to increased demands for its various products as wood fuel, construction materials, ecotourism and water provisioning that is likely to further degrade them. The widespread believe that forests reserves are potential areas for settlements and infrastructural development is still widely held by many people in the region. Some of the outcomes of the perception are legal and illegal conversion of forests agricultural land through cultivation, grazing and permanent settlements or dam construction or road bypasses or schools. Land and natural resources are some of the goodies that are often offered for political and economic reasons lend itself to various political interference and influence peddling and sophisticated networks that continue to extract various products from forests within the eye of powerless government agencies and communities adjacent to the forests. The long term nature of forest enterprises make financial institutions give a wide berth consequently mobilizing financial resources for investment in forest enterprises remain a challenge to many potential investors. Tree plantations are subjected to a number of social risks such as arson, and deliberate vandalism in situations where there are conflicts over land ownership and use.

Some agricultural policies such as subsidies on fuel and fertilizer and high prices to boast agricultural production leads to fast rate of conversion of forestlands to agricultural enterprises. Plantation monocultures tend to be more vulnerable to pest and disease attack and can frustrate the tremendous efforts and resources that have gone into establishment of commercial forest plantations in the region. The number of tree pest and diseases and rate of spread in some cases has been worrying because in some cases little is known on distribution, host range, population variability and magnitude, making it problematic to effectively control them. The region have not put in place structures to enhance traceability and transparent mechanism such as chains of custody hence cannot access international markets that require certified products.

Primary Production

The countries in the region produced various products from the local forests that included saw logs/peeler logs, various types of poles, charcoal and firewood. In terms forest ownership Tanzania lead with over 48 million hectares, Kenya (38,412,000), Sudan (18,197,000), Uganda (3,604,174) and Rwanda the least with only 240,746 hectares in the order (Table 2). The countries in the region still rely on firewood and their consumption estimates correlated with the available forest resources and population size for each country. Public and community forests provided the bulk of the stocks used for production of charcoal and firewood. Similarly, the available stocks for sawn and peeler logs were mostly sourced from public plantation forests but private forests are the new frontiers to fill the shortfall in timber supplies in the regional demand centres. The private sector investors include leading wood based companies, syndicated private investors and large scale farmers that were attracted by lucrative business in trees based enterprises. In Eastern Africa private investors have invested in fast growing short rotation species mixes for various purposes and their plantations have grown faster than public sector plantations especially in Tanzania and Uganda. The productivity of plantation forests is highest in Kenya at 385 m^3/ha as compared to the rest of the countries in the region. The plantation stock levels that supply industrial round wood indicate that Kenya and Uganda lead the rest. The study revealed that the private sector investors deployed integrated utilization processing and value addition to minimize wastage and improve their operating profit margins. In Kenya the private sector business model is largely a diversification strategy from core agricultural based business into profitable forest enterprises that takes both vertical and horizontal integration dimensions depending on the core business of the investors. In some countries like Kenya, large wood based companies purchase land for tree growing but shortage of land and high prices caused by severe competition from agricultural enterprises and settlements. In Uganda and Tanzania, the private sector has been able to lease land from public and community forest reserves to establish commercial plantation for own use and surplus for release to the local and export markets. In Sudan the Forest National Corporation (FNC) and communities are engaged in joint management of degraded forest on cost-benefits sharing arrangements that is aimed at improving primary production in public forests. In Eastern Africa, the move to involve communities, individuals and private sector players in primary forest production is growing and likely to become a permanent feature that will leverage on efficiency in land use, efficient technologies and high demand for forest products to compete in local and regional timber markets.

Table 2. Forest size and primary productions for key products

Country	Total Forests(ha)	Productivity m^3/ha	Sawlogs (m^3)	Poles (m^3)	Charcoal (m^3)	Firewood (m^3)
Kenya	38,412,000	385-503	7,363,414	3,0328,907	7,358,717	13,654,022
Rwanda	240,746	150-220	961,927	-	48,000	5,000,000
Uganda	3,604,174	68-290	3,250,000	1,531,000	16,684,000	38,858,000
Sudan	18,197,000	-	9,800	298,000	173,000	286,000
Tanzania	48,702,000	37.7-171	58,004	-	17,546939	51,000,000

NB: (–) in where it is non-existent or information not provided.

Secondary processing and manufacturing

Secondary processing and manufacturing of wood products involves transformation of round wood into various products such as sawn wood, furniture and wooden interior fittings, paper and paperboards, ply woods, doors, carvings and windows. Except for saw milling, transmission pole treatment plants and industrial biomass energy production most woodwork activities are more of cottage industry than manufacturing (Table 5).

Sawmills

Sawmilling is the dominant forest industry in the region that is more developed in countries with vast plantations such as Tanzania, Kenya and Uganda. The sector is usually classified into three categories based on processing capacity into large, medium and small size-saw mills. However, in term of product lines sawmills are categorized into those which produce sawn timber (both treated and untreated), value added products and dry timber. Table 4 indicate that Kenya had the highest number of registered saw mills that number 633, Uganda (180) and Tanzania (520). Tanzania host the largest saw mills in the region with Sao Hill industries leading with capacity to produce 48,000 m^3 Kilombero Valley Teak - KVTC (45,000 m^3) and TANWAT (20,000 m^3). In Kenya the saw milling sector used to employ about 300, 000 people in forest and wood processing operations, transportation and other supporting services before the logging ban in 2002. Similarly, in Tanzania and Uganda saw milling employ thousands people in logging, sawing and transport sectors. Kilombero Valley Teak company owns the largest teak-processing sawmill in the world (KVTC, 2015), which is integrated with a drying facility and processing plant. The range of products from saw mills include sawn timber, floorings, cornice, and panels. Most countries produced sawn wood for local markets except for Tanzania that realized surplus that was exported to eastern and southern African countries. Saw mills deploy a wide range of machines from simple machines that include power saws and bench saws to gang or band saws and wood-mizers. Large and medium scale saw mills deploy the most advanced technologies with high recoveries as compared to most small scale saw mills that are equipped with inefficient and wasteful technologies whose conversion efficiency ranges between 26-35 %, thus about 70 % of wood is wasted. Mobile power saw are the most inefficient with an estimated recovery rate of 25 %.

Paper and Paper Products

Pan Africa Paper Mill (PPM) in Kenya is the largest in the region with installed capacity of 100,000 MT of paper products and intake of 500,000 m^3 of pulpwood and 250,000 m^3 of firewood per year. The second mill is the Mufundi Paper Mill (MPM) in Tanzania with capacity of 46,000 tonnes. The region depending on round wood supply potential still have room for more industries to meet growing need for paper and paper products. The region also has many small-scale paper manufacturing plants that utilize recycled paper and among other materials. In Kenya there were 13 paper products manufacturing mills that use recycled paper to produce various paper products key being Chandaria Industries located in Nairobi, and Highland Paper Mill located in Eldoret, among others.

Reconstituted wood products

The reconstituted wood sector in the region is dominated by three Kenyan based industrial complexes the Rai Ply, Comply and Timsales that are involved in integrated wood processing consisting of saw milling, plywood and particle boards manufacturing. Other diversified products include chip boards, block board, hard boards, melamine, machined timber, furniture, flooring tiles, and MDF. The complexes have also expanded their operations into Tanzania, Uganda and Malawi. In Tanzania, Tanganyika Wattle Company (TANWAT) produces 40,000 pieces of plywood per year. In Uganda Nile Ply and few small sized plywood mills that utilize small woods are in operation mostly deploying inexpensive Chinese machinery and manual processing mostly for domestic markets.

Domestic and institutional firewood

Firewood is the leading forest product in terms of volumes consumed mostly for domestic and institutional (schools, hospitals) use that accounts for 94 % or 34.3 million of round wood extraction from forests and woodlands in Kenya. The countries in the region also heavily rely on firewood hence high consumption rates that will still grow even with promotion of cleaner energy sources due to cost and access to such alternatives.

Industrial firewood

In the region, key users of industrial firewood are textile, food and chemical processing industries and recently generation of electricity. Kenya reported a diversified industrial consumer that include tea sector that consist of 94 factories with annual intake of 1,592,000 m^3 with an estimated value of USD 22 million. Tanzania and Uganda also have tea factory that use firewood in tea processing. Others industrial uses of firewood in the region include tobacco curing, textile and food processers mostly in Kenya.

Production of charcoal

Charcoal production is the second largest consumer of round wood in the region after firewood. Roundwood demand for charcoal production in Uganda, Sudan and Tanzania was estimated at 11 million, 49 million and 17.5 million m^3 per year respectively. Kenya consumes about 16.5 million metric tonnes translating into 240,000 hectares per year. The charcoal production is dominated by small scale and irregular producers deep in the rural areas. Charcoal in the region is an important source of energy for cooking for most urban and rural households and a highly traded forest based commodity. Except in Kenya and Sudan where pockets of sustainable production of charcoal from *Acacia mearnsii* and various indigenous Acacias respectively exists, most charcoal in the region is produced unsustainably from woodlands and bushlands of the ASALs. The charcoal production projection indicate progressive fall in supplies in major production areas in the region mostly attributed to decline in trees populations available from woodlands and farmlands. The forecast indicate that the charcoal market demand will remain unmet. Charcoal production in the region still remain a wasteful process with conversion efficiency of between 20 % and 30 % indicating over 70 % of the wood materials are lost. The charcoal production and marketing is big business that employs thousands of people and generate high incomes to key players in the market value chain in Uganda, Sudan and Tanzania. In Kenya annual charcoal demand is estimated at 2.4 million and 2.3 million metric tons. The sector in Kenya is reported to earn USD 530 million per year and support directly 200,000 producers and indirectly 700,000 persons employed in the market value chains with an estimated 2 million dependents (Wamugunda, 2014; Cheboiwo and Mugo, 2012; ESDA, 2005). In Tanzania the annual charcoal demand is estimated at 3.3 million tones with a value estimated at US$500 million (Sawe, 2009).

Wood carving

Traditional wood carving has been an integral form of artistic expression and use among the communities in Eastern Africa especially among the Makonde and Zaramo of Tanzania and Kamba in Kenya. Kenya has the most established wood carving industry in the region that revolves around key production sites mostly Wamunyu in Machakos County and Ukamba Wood Carving Cooperative Society (UWCCS) in Mombasa Town. The wood carvers prefer specific tree species mostly indigenous species for carving such as *Dalbergia melanoxylon*, *Terminalia brownii*, *Afzelia quanzenis*, *Jacaranda mimosifolia* and *Combretum schumannii*. The sector in Kenya is estimated to employ about 60,000 people with an estimated export value of US$20 million (Choge, 2002; Cunningham *et al,* 2007). The major market destination for Kenyan wood carvings is mostly the U.S., United Kingdom (U.K.), Sweden and Norway. Currently, the wood carving sector is facing several challenges that include shortage of quality wood, ban on harvesting in natural forests, green consumerisms in western countries, and competition from other countries that has seen production and its export markets shrink by 75 % (Hamilton, 1996) that may likely have worsened into the future.

Construction poles

In the region construction poles are used in a variety of activities such as low cost construction works such as scaffolding in high-rise buildings and construction of mud houses and kiosks. Construction poles also form the bulk of the materials used in expanding slum areas in major towns. Construction poles are bulky and low value end products that tend to be supplied from adjacent areas to consumption centres. Construction poles are mostly produced from farms from various species such as Eucalyptus, Pines, Cypress and many indigenous species. In the coastal region of Kenya *Casuarina equisetifolia* poles are in high demanded for construction and renovation of *makuti* buildings popular with tourists. The demand for poles has been on the increase due to vibrant construction activities taking place in many towns that require poles for scaffolding and props. In Kenya the annual supply of poles is estimated at 3,028,907 m^3 (MEWNR, 2013).

Transmission poles

The use of wooden poles to transmit power and telecommunication has long history that has supported growing and processing transmission mostly in Kenya, Uganda and Tanzania. The sector has witnessed fast growth in the last decade with expanded power generation and distribution. For example, in Kenya, there were only 2 treatment plants in the country capable of processing 160,000 power transmission poles per year in 2004 that grew to 55 by 2015 with capacity to process 2 million poles per year (Cheboiwo, 2016). The wooden transmission poles sector is valued at USD 64 million (KES 6.4 billion) spread across tree growers, logging, treatment plants and transportation. However, the utilization capacity has remained low due massive expansion of processing capacity that has created severe competition and stagnant national demand capacity of 600,000 pieces per year. Others include unpredictability of tendering process of key Kenya Power and (KPLC) and Rural Electrification Authority (REA) that make it difficult for manufacturing plants to synchronize acquisition of semi-processed poles and import of treatment chemicals from overseas suppliers. Similarly, the sector has grown from one treatment plant each Uganda and Tanzania in 1999 to 5 and 12 by 2016 with production capacity of 475,000 and 520,000 respectively mostly for domestic use and surplus for export to Kenya.

Furniture and joinery

Furniture and joinery are some of the most vibrant enterprises owing to the fast growing construction sector and increasing urban population as well as improved affluence linked to growth of the economy. The sector is characterized by hundreds of micro, small- scale units and few medium scale units located in rural and urban areas as formal and informal businesses. The furniture making is a labour-intensive, low-startup costs and it can be operated both in rural and urban areas (Indufor 2011). The less stringent and enabling characteristics of the industry make it a potential employer of most youths who leave primary and secondary schools and that find themselves jobless thereafter. Softwood and hardwood timber are commonly used mostly sourced from cypress, pines, eucalyptus and mahogany. Due to shortage and high cost of premium timber some furniture makers have resorted to low cost and poor quality timber sourced from mango (*Mangifera indica*), Eucalyptus, *Grevillae robusta* and even *Avacado* (*Persea americana*) that were never used for furniture in past. In Kenya furniture and joinery is reported to rely on hard work and ingenious use of resources to survive and is estimated to consume 262,442 m^3 of timber per year with coffins taking up 184,800 m^3 (Githiomi, 2010). The sector supports about 160,000 people in the forestry and manufacturing sectors of the economy. The sector is highly diversified with different types of machines in use ranging from imported to locally fabricated wood lathe, bench/handsaws and clamps among other tools and equipment. The sector supplies the needs of the local people and limited exports. In Kenya the furniture businesses are concentrated in Jogoo Road, Ngong Road and Industrial of Nairobi. In Tanzania furniture business are organized in clusters within

Dar es Salaam such Keko, Manzese, Kinondoni-Biafra and KinondoniMoroko. These clusters engage between 10 people in Manzese to close to 1000 in Keko. In these clusters, some work as producers of furniture while others are sellers or brokers of furniture. The product lines are so diverse. They include home and office furniture, parts of furniture and of recent is the upcoming, metal furniture. In Uganda NAFA (2009) report indicate that there are many groups of individuals involved in furniture and joinery with clusters in Ndeeba and Bwaise in Kampala city. This section of the industry plays a critical role of supplying low-cost furniture products while providing employment opportunities to marginalised groups, particularly youths and women. There is however a number of medium sized firms employing relatively advanced technology to produce high-class furniture. These include Hwang Sung Furniture Company, Elimu Furniture Company, Lotus Arts, Kaava Furniture Company, and Master Wood Furniture Company (Kizito, 2009). The annual furniture sales in Kenya is estimated at US $ 496 million with an estimated annual growth rate of 10% and import and export values of USD 66 million and 22 million respectively (World Banks, 2014). The same study estimates that the East African furniture market is valued at US$ 1.2 billion whereas the regional trade is worth paltry US$ 298 million per year. Therefore, the sector needs urgent reforms to address quantity and quality material supplies, appropriate technologies, skilled manpower and incentives to attract investments.

Non-Timber Forest Products (NTFPs)

The region due to diversity of forest resources and ecological ranges produce a wide range of non-wood forest rattan & bamboo, aromatic oils, bee products, herbal medicine, wild coffee, mushrooms, wild fruits, gums, tannins, Prunus bark and resins. These products are harvested and processed by small-scale harvesters and offers opportunities for improving livelihoods for rural communities living close to forest resources. NTFPs are easily accessible, require little capital investment for collection, processing and marketing, while their production is relatively less destructive compared to timber. In the dryland woodlands some of the key NTFPs include myrrh, baobab fruits, tamarinds, aloes and shea butter. Generally, major actors in NTFP extraction are the communities living around forests who harvest the products individually or as a community depending on local arrangements. In Kenya Prunus bark annual bark export potential is estimated at USD 17 million and gum arabic exports from Sudan and Kenya is estimated at 30,781 tons and 3,000 tons valued at USD 454 million and 14 million respectively. The beekeeping sub-sector is another potential employer. In Tanzania the sector generates about US$ 19 million per annum and employs some 2 million people but holds greater potential given that the country has only exploited 3.5 % of its production potential (MNRT, 2001). Tannin production from *Acacia mearnsii* is another important activity that supports 3 factories in Kenya and 2 in Tanzania with estimated annual outputs of 46 tons and 2810 tons respectively. The tannin production in Kenya fell from 25,000 tons in 1998 to 5340 tons by 2003 and paltry 46 tons by 2015 despite the growing demand from vibrant leather industry demand estimated at 10,000 tons. The country imports bulk of it tannin from Tanzania.

Organization and linkage among actors

In general, the forest sectors actors are largely disaggregated with limited vertical and horizontal integration except for some few corporate players in the primary sector that have pursued a strategy of vertical integration. Most of the primary associations are at infancy stages still being supported by government and bilateral agencies. The main objectives of such associations are to influence policy and legislation, support members in technical issues, marketing and sharing experiences amongst members. However, most actors in the forest production sector operate on an individual basis and do not belong to trade associations. Some actors are engaged in informal networks and contractual arrangements. In Sudan the Gum Producers Association, the largest producer group in the region, is an umbrella association representing over 1344 individual groups with 99096 members managing forest estimated at over 6 million hectares.

In Kenya there are two apex tree growers associations namely Farm Forestry Smallholder Producers Association of Kenya (FF-SPAK) for smallholder and Kenya Forest Growers Association (KEFGA) for large scale tree growers. KEFGA is better organized with well-structured national office bearers and its members pay registration and annual subscription fees based on forest woodlots size. Charcoal Producers Associations (CPAs) is another umbrella body that brings together charcoal producers that is the outcome of the subsidiary legislation the Charcoal Rules 2009 to promote sustainable charcoal production in the country. Timber Manufacturers Association (TMA) formed in 1981 is another umbrella group that represent the interests of saw millers countrywide. Kenya Wood Preservers Association (KWPA) is a membership organization that draws members from wood treatment plant owners and suppliers of treatment chemicals whose objective is to promote the preservation of wood in the country to international standards for longevity in use, convenient to use and attractive to customers. The KFS under Forest Act 2005 has entered into participatory Forest Management (PFM) agreements with registered 97 Community Forest Association (CFAs) countrywide to manage 1,000,000 ha of forests but sharing of benefits remain a contentious issue.

In Uganda, the Uganda Forestry Working Group (UFWG) is a network of CSOs, academic and research institutions with the mission of promoting the development of the forestry sector and stimulating forestry stakeholders to respond to sector changes and challenges. Uganda Timber Growers Association (UTGA) formed in 2006 comprise of individuals and firms engaged in development of timber industry in the country. The association was formed in 2006 and now boasts of wide membership including small, medium and big planters across Uganda.

Tanzania has the widest range of organized players in the primary forest production that include Federation of Small-Medium Forest producers (SHVIMITA), Sao Hill Forest Industries Association (SAFIA), Northern Forest Industries Association (NOFIA) and Tanzania Private Sector Development whose members range from individual investors in forestry sector to large, medium and small scale companies. The forest based companies include Mufundi Paper Mills (MPM, Fibre Bard Africa Ltd (FAL), Tanganyika Wattle Company (TANWAT), New Forest Company (NFC), Kilombero Valley Teak Company (KVTC) and Saohill Industries Ltd (SHI). Smallholder tree growers associations include 150 tree growers associations (TGAs) most still at formation stages with the support of the Private Forestry Progarmme (PFP). KVTC supports tree out-grower schemes through supply of quality seedlings, fertilizer and purchase of logs. In the furniture sector, the apex body is the Tanzania Wood Working Federation that represents all wood furniture makers but is more active in Dar es Salaam with minimal presence in the regions. In the wood carving sector the Makonde Handicrafts in Dar es Salaam represent wood artisans and handcart sellers in Mwenge and Kinodoni district of Dar es Salaam with smaller groups in Lindi, Mtawara, Morogoro and Ruvuma. The collaboration between community and government under joint forest management (JFM) and participatory forest management (PFM) is one of the largest in the region covering 1,052 villages and covers forest area of 5,392,095 ha. Under JFM and PFM, communities and the government enter into agreement to co-manage specified forests. Except for GAPAs other linkages within the forestry sector is weak especially NFC, forestry education institutions and forest research institutions despite signed memorandum of understanding. It is proposed that such critical linkages should be mandatory with supportive legislations but not left to the whims of individual employees of the institutions.

Gender and forest production

The study acknowledges the fact that men, women and youth have different gender-based responsibilities, needs and priorities, as well as knowledge of, access to and control over the local environment and forests in particular. In Sudan women are involved in gathering of food, fuelwood, fodder, medicinal plants and raw materials for small industries. Men are generally engaged in large scale firewood collection and charcoal production mostly for sale. In general, women are excluded from decision and policy-making process at local and community levels. However, at professional level, we have seen the proportion of women among professional foresters in FNC and its provincial administrations is reasonably high and they take active role in decision making.

In Kenya, traditional customs and conventional policies and legislations guide gender related land control and access to forest resources on day today basis. Therefore, participation of women in forestry cannot be complete without reference to prevailing land tenure systems, and women’s rights to access, use and ownership of land. Although existing policies and legislations are not primarily discriminatory in regards to women owning land, the World Bank Report (2007) shows women owned only 1.5 % of all titled land in the country that attests to the property relationship between men and women mostly shaped by traditional customs and marital arrangements despite the fact that 30.9 % of households in the country are female-headed (CBS, 2006). In most cases land asset ownership in rural areas is transferred through males in the family tree. Therefore, Women currently face natural resource and asset vulnerabilities because their access rights are still dominantly related to kinship and marital relationships. However, women participation in employment opportunities in primary and secondary production are only limited by few factors such as time available outside family commitment and strenuous menial challenging jobs such as logging and heavy machine operations. However, women dominate in some key primary production activities such tree nurseries and forest products market value chain such wholesaling and retailing in both urban and rural areas of such products as firewood, charcoal and NTFPs related SMEs.

In Uganda the Land Act (1998) provides for non-discrimination against women but gender disparities in land ownership persists as only 7 % of the land in Uganda is owned by women (Mukasa *et al.*, 2012). This is because most land in Uganda is acquired through inheritance, which favours men over women. In addition, under most land tenure systems, women's rights to land are largely limited to usufruct rights. This is a barrier to women's participation in production forestry since most of them do not own land and have to first seek for consent from their spouses if they want to plant/sell trees. Women's limited control over productive resources also affects their access to credit facilities that are crucial for investment in tree planting. It is generally believed that forestry is a male domain because men do most of the work in tree planting activities in terms of clearing land, acquiring seedlings, planting, weeding and management. However, despite beliefs that women lack physical strength and courage required for most non-managerial forestry jobs, women constitute a significant proportion of the work force in the forestry sector (Mukasa *et al.*, 2012).

In Rwanda, forests resources decrease often severely increases women's labor, especially with regard to the time required to gather firewood and the cost of purchasing it hence negatively impacting household nutrition. The country policies and legislations promote equality of men and women in all socioeconomic activities including forestry. However, equality study showed that there is inequality of gender participating in agriculture, fishing and forestry where male represent about 82 % compared to women (61 %).

The Tanzanian report shows that men are more dominant in production of charcoal and bee products while women dominate firewood collection (MNRT, 2014). In forest-related institutions female employees are fewer than men especially at the managerial levels. The same is replicated in enrolment in forestry training and higher learning institutions. However, in recent years, there has been a remarkable improvement in women enrolment particularly in higher learning institutions. For example, in Tanzania, Sokoine University of Agriculture (SUA), female enrolment into BSc Forestry constituted 25 %, 29 % and 22 % in 2013/2014, 2014/15 and 2015/2016 respectively compared to men and to 7 % enrolment reported in 2013. In tree growing associations (TGAs) on average, women make about 35.7 % while men take up the remaining 63.4 % of all TGAs members (MNRT, 2011). However, women involvement in TGAs leadership which consists of a chairperson (0 %), secretary (18 %), and treasurer (82 %) (Vainio-Mattila, 2011). Therefore, the roles of gender in forestry evolve over time in response to changing circumstances, needs and interests and as forests grow, shrink, change and shift, so gender roles and relations also undergo constant renegotiation.

Policies and legislations in relation to PPPs in forest sector

Public Private Partnership (PPP) is an arrangement whereby the private entities invest, manage and assume service delivery in public sector property for a significant period of time and in return, receives benefits/financial remunerations according to agreed terms. PPPs are therefore a cooperative venture built on the expertise of each partner that best meets clearly defined public needs through the most appropriate allocation of resources, risks and rewards. Eastern Africa countries have enacted policies and legislations that support PPP implementation in the forest sector. However, the political, policy and legislative frameworks are more favourable to high cost infrastructure development such as petroleum pipelines, ports, roads, tourism, housing, railways and water and sanitation. However, the forest sector have put in place some policies and laws that relate to some variants of the PPP. In Kenya the supporting instruments include the multi-sectoral PPP policy 2013, PPP Act of 2013, National Forest Policy 2016 and Forest Conservation and Management Act 2016. The Forest Act 2016 sets out conditions for forest concessions and management agreements for private sector players and proposes development of subsidiary legislation to operationalize the concessions. The 6th principle of the Draft Forest Policy 2016 states that the government will encourage private sector participation in the establishment and management of forest plantations on public and community land through granting of concessions on a competitive basis. However, no such concession has taken place so far. In Tanzania the main PPPs type in the forest sector is investment in existing public assets that is well supported by the Forest Policy (1998) and the Forest Act (2002) through participatory Forest Management (PFM) and concession arrangements. In Uganda the PPP engagements are supported by various instruments that include framework policy (2010), the Public Private Partnerships Act (2015) and guidelines on Public Private Partnerships for Local Governments. The Forest Policy (2001) emphasizes the important roles the private sector will play in developing and managing commercial forestry plantations in the country. The key areas for PPP consideration include forest management and utilization. In general, most countries in the region have policies and legislation in place to support PPPs in the forest sector. However, the study confirmed that despite some countries having favourable policies and legislative framework to support PPPs all the countries studied had no forestland concession in operation due to lack of specific legislation on forest concession in place. However, land leases for plantation development are in place in Uganda and Tanzania.

Potential Forest PPPs sector

In Kenya, existing forest sector PPPs are more focussed on corporate social responsibility (CSR) activities such as provision of financial support for awareness creation and rehabilitation of degraded forests and putting up of electric fences to keep wild animals away from farms to reduce people and animal conflicts mostly in the country's key water towers. Some specific CSR initiatives include construction and maintenance of electric fences to protect Mount Kenya forest, Arabuko Sokoke forests in Kilifi and Eburu forest of East Mau Forest block. Some variants of PPPs include private sector support to rehabilitation of key water towers through putting up governance structures and mobilization of finances through innovative mechanisms such as the marathons. Key among the marathons are Ndakaini Dam Marathon (Aberadres forest ecosystem), Mau Forest Marathon (Mau Forest Complex) and Cherangany Forest Marathon for Cherangany Hills ecosystem. The private sector players include telecom, insurance, financial, tourism, and banks among others. The awareness campaigns have enhanced the visibility of key waters towers to greater public and activities have enhanced forests conservation

In Sudan, Forest National Corporation (FNC) has been working closely with farmers and local communities in rehabilitation of degraded forests. This is because it is unable to implement large scale forestry programmes due to inadequate human and financial resources.

Some of the successful collaboration includes Wad Annial Shaggat community forest reserve in Sinnar State that covers an estimated 67,000 ha where village communities are allowed to cultivate crops, graze their animals, tap and collect gum arabic from *Acacia Senegal* trees. In Hawata area, 250 ha of trees are under community 20-year management plan where they are allowed to cut about 12.5 ha every year for sale to invest in village services such as construction of embankment to protect the village from river flood, schools and mosques. In Hawata area a total of 615 ha occupied by *Acacia seyal*, *Acacia mellifera, Acacia Senegal* and *Acacia nilotica* is jointly managed by a private investor in accordance to approved work plan with the technical advice from FNC regional staff. The private investor is allowed to cut 25 ha per year. For sale as firewood, and conversion to charcoal and the revenue generated is shared with the regional forest office as royalties.
In Rwanda, the government is making efforts to build public-private partnerships to complement its efforts in forest protection and conservation, forest establishment and management, processing, value addition and trade with the aim of ensuring the long-term and sustainable supply of forest products and services. Presently, the private sector participation is biased to forest based industries, small scale processing, manufacturing and trade with limited participation in primary production. The National Forestry Strategy clearly emphasizes public private investment in forestry through 7 out of 14 principles that guide the implementation of the strategy. These principles include sustainable forest management (SFM), commercialization of forestry operation, stakeholder involvement and partnerships and private sector involvement in forest management and processing of forest products, leaving the public sector only the regulatory function, research and quality assurance.

In Uganda, some of the many variants of PPPs currently operating in the forestry sector include initiative between the Government of Uganda (GoU) and Forests Absorbing Carbon Emissions (FACE) that involve rehabilitation of 10,000 ha of degraded forest areas in Kibale and 25,000 ha in Mt Elgon National Parks. Another is the World Bank Biocarbon Fund and the Government of Uganda in conservation of the Rwoho CFR in Mbarara District in collaboration with local communities. The International Small Group and Tree Planting Programme (TIST) is ajoint initiative of the Institute for Environmental Innovation (I4EI) and Clean Air Action Corporation (CAAC) that operate in three sites (Bushenyi, Kabale and Kanungu) to empower small groups of subsistence farmers to rehabilitated degraded forests and tree planting and sustainable agriculture. Under PFM framework several communities are engaged in a Collaborative Forest Management (CFM) arrangements with NFA to manage Central Forest Reserve (CFR) in which rights, responsibilities and returns for the communities include access to forest products such as firewood, medicinal extracts, herbs, ropes, building poles, vegetables, etc. CFM arrangement is being implemented in Budongo, Bugoma, Mabira, Echuya, Kasyoha-Kitomi, and Sango Bay forests. The Saw Log Production Grant Scheme (SPGS) is a joint initiative between the Government of Uganda (GoU) and EU that is involved in building capacity of private tree growers in commercial tree growing in CFRs. So far some 44,166 ha have been established to the required standards and extra 30 000ha are targeted. Tree growers are provided with technical knowledge and financial assistance (rebates) that are critical to the success of plantation development. Another variant of PPP being implemented by NFA and private sector players, in line with policy statement 3 and 5 of the Uganda to lease parts of the central forest reserves for private plantation development under fast maturing species particularly Pine and Eucalyptus.

In Tanzania, PFM and joint forest management (JFM) is anchored in the Forest Act of 2002, which provides a clear legal basis for communities, groups or individuals across mainland Tanzania to own, manage or co-manage forests under a wide range of conditions. The co-management of forests between government and communities is not popular most communities because of lack of clear-cut cost-benefit sharing mechanism between the parties. The principle of fair, social inclusion community welfare and arrangements are not provided for in the law (Simula and Kaduvage, 2005) but some of them that hold good potential include: JFM between central government and TGAs. TGAs are new but upcoming players in the forest sector; JFM between village governments and TGAs or between Community groups and TGAs and out-grower arrangements between tree farmers or TGAs, and wood based companies. The leasehold agreement between community groups and private companies are the most successful PPP variants in Tanzania where the two parties enter into an agreement where the government retains the guarantor status for such agreement. Many international investor syndicates, companies and individuals have entered into leasehold arrangement that has put hundreds of hectares under forest venture in the country. Under the leasehold schemes Green resources has established 12,000 ha of plantation forest in Iringa Province. In the same region Mufindi Pulp and Paper Mill has established 3,000 ha with between 30-40,000 land reserve available for future plantations. Others include Kilombero Valley Teak Company (KVTC) with 8,162 ha of teak plantation and TANWAT (14,000Ha). These arrangements look more likely to improve social inclusion, address gender aspects and enhance the livelihood of the communities especially when they operate within the boundaries of bylaws set by communities themselves. Forest Policy (2009) and Forest Act (2002) provides for forestland concessions whereby the private entity is granted exclusive rights to provide, operate and maintain forests over for a long period of time in accordance with performance requirements set by the government but the public sector retains ownership of forestland while the private entity retains ownership plantations established during contract period. In Tanzania there is no forest concession in operation (Ngaga, 2011) and if one was operational, mechanisms for monitoring forest concession are not available (PFP, 2015). However, land leases and permit instruments are in use for plantation development in Uganda and Tanzania that has seen many international investor syndicates, companies and individuals establish hundreds of hectares of private plantations. In Tanzania, Green Resources Mufindi Pulp and Paper Mill, Kilombero Valley Teak Company (8,162 and TANWAT among other investors have established 44,222 ha and in Uganda Green Resources, New Forests, Global Woods and Nile Ply among others have established 44,166 ha of plantation in public forest reserves.

Present and projected wood production and demand

According to projection for the countries in the region, the supply and demand for various forest products indicate growing deficits in the next 20 years and into the future. Table 3 show that supply and demand projection clearly indicate that the all the countries will face acute shortage of forest products in the near future. Therefore, there is need to intensify productivity in public forest plantations and as well bring on board the private and farm forestry sector into the national wood supply grid. The nascent private sector and farm forestry are the only potential sector that may realize some significant growth in both land areas and production but such expansion will be checked by the severe competition from agriculture and settlements. Another promising option is private sector through leasing or concession of public forest reserves to private sector investors to establish plantations and put in place integrated utilization procedures. The private sector profit driven investment in primary production will enhance plantation productivity and processing operational efficiency that will put more wood into the market than under public sector mismanagement.

Table 3. Wood production and consumption in m^3

Product	Kenya	Uganda	Tanzania	Sudan	Rwanda
Production 2015	31,953,470	51,652,000	89,350,000	10,931,000	5,432,000
Production Projection 2030	61,021,000	73,386,000	89560,000	4,387,000	7,603,000
Consumption 2015	43,289,150	2,693,000	40,140,000	25,128,000	3,244,000
Consumption Projection 2030	65,058,400	10,434,000	71,102,000	38,217,000	5,248,000

Economic importance of forestry

In the region forest resources are some of the most important natural assets that produce a wide range of ecological, economic, social and cultural products and services for multiple stakeholders. Forestry sector contribution to the national GDP various between the countries in Eastern Africa that range from 10.6 % in Rwanda, 3.6 % in Kenya, and 4.5 % in Uganda (Table 4). In the region, it is estimated that over 90 % of households depend on biomass energy most of which is in the form of firewood and charcoal derived from these forests. In Uganda, forests offer many opportunities for poverty alleviation, economic development and environmental improvement for estimates put the annual turnover of businesses in the forestry sector such as charcoal, poles, timber, furniture, crafts, firewood, fruits and seedlings at over $100 million and employs over 1million persons (UBOS, 2010). In Kenya, the forest sector is estimated to employ over 1 million persons in firewood, charcoal, saw milling and wood carvings market value chains. The forest sector turnover for various sectors is estimated as follows: Charcoal market value chain is valued at $530 million) employs 700,000 people; Saw milling employs over 300,000 persons and its outputs is currently valued at $37 million; market for furniture is valued at $496 million while employing over 160,000 persons; Wood carving employ 50,000 persons and is valued at $220 million; transmission poles sector is valued at $69 million, industrial firewood for tea processing is valued at $22 million and guns and resins exports are valued at $0.36 million. The country is the largest market for furniture, paper and paper products and wood panels from Asia and Europe. Therefore, the deficit in both primary production and manufactured wood products provides huge opportunities for investors in primary production and secondary production sectors include trade in various forest products. In Rwanda the firewood and charcoal market value chain support 50,000 households approximately 2.8 % of the entire population and its annual estimated value is USD 2.6 billion (BEST, 2009). Studies show that tree growers earned 22 % of the consumer prices, charcoal burners (7 %), transporters (10 %), wholesalers/retailers (13 %). In Kigali it is estimated that more than 30,000 families are dependent on charcoal business. The tourism and ecological potential of forests are also estimated to be high in terms tourist attractions, hydroelectric potential, and support to agriculture and carbon sequestration. In Sudan the contribution of gum arabic to the world market stand at 52 % at present and forest sector contributes annual 10 % to the country's GDP (Nour H. O A.(2014).Tanzania is an important player in forest production and trade in the region. The forestry sectors through its various commodities production to consumption market value chains annual support employment opportunities for over one million persons. The forestry sector contribution to GDP is estimated at 13 % which is relatively high in the region.

Table 4. Forest sector contribution to the GDP and employment

Product	Kenya	Uganda	Tanzania	Sudan	Rwanda
Employment	1,000,000	1,000,000	1,373,000	-	100,000
Value USD	785,440,000	-	-	-	2.6 billion
GDP	3.6	4.5	13	10	10.6

NB: (–) in where no information was provided.

Trade in forest products

Most of the countries in the region are net importers of tree products mostly manufactured paper and paper boards and plywood, among others products. Kenya despite being the most industrialized in terms of the number of wood based industries in the region remain a net importer of various products that include timber, paper and paper products, wood based panels. The exports included paper and paper products, wood based panels and pulp and recovered paper. For example, in 2014, Kenya imported 47 million metric tons (MT) of wood based panels and exported 3.5 million metric tons of the same. In the period 2010-2015 the value of imports was USD 1.8 billion as compared to USD 350 million worth of exports (Cheboiwo and Kiprop, 2016). The trend in imports on average is on the upward trends whereas exports are on downward trends indicating the country's balance of trade in forest products is negative. The exporters of forest products to Kenya include China, South Africa, Malaysia, Tanzania, Turkey, Germany, Thailand, India, USA and Sweden among many others countries. Kenya exports various wood products which include cork, wood carving, paper, wattle bark extract etc. These include Sudan, Democratic Republic of Congo, Rwanda, South Africa, Uganda, Tanzania, Ethiopia, Cameroon, Zimbabwe and Western Sahara. Kenya also exports to other parts of the world namely Israel, Italy, England, Belgium, Norway and China. Tanzania is one of the key exporters of various tree products in the region mostly to Europe and Asia that has been dcelining as compared fast growing exports to Eastern and Southern Africa countries. The range of products exported from Tanzania include roundwood, paper and paper board products and wood articles. However, sawnwood exports fell from 280,564 m3 in 2012 to 166,878 in 2014 and value from USD 12.6 million to 10.5 million in the same period. Similar trend was also observed for honey (Table 5). In Sudans the major export commodity was gum arabic that on average was 30,781tons with a value of $45.4 million.

Table 5. Forest product trade and values in USD in 2016

Product	Kenya	Uganda	Tanzania	Sudan	Rwanda
Quantity imports	-	6906 m^3		-	6,000m^3
Value of imports*	241,336,181	-	51,500,000	20,000,000	-
Quantity export	-	-	58.67 m^3	30,781 tons	-
Value of exports	40,841,099	-	63,820,000	45,400,000	-
Sawnwood exports	-	-	166,878 m^3		452 tons
Value of exports	-	-	10,500,000		-
Sawnwood imports	38,506 m^3	-	-	-	-
Value of imports	28,900,000	-	-	-	
Honey export	-	-	0.85 tons	-	-
Value of exports	-	-	203,573	-	-

#Gum Arabic

NB: (–) in where non information was provided.

Conclusions

- The most productive forests in the region are located in the high and medium potential agricultural zones that fall under private and public ownerships but the largest category of forests the woodlands are located ASALs mostly owned by communities and local governments.
- The key actors in primary and secondary forest production are many and in some cases unique to some countries. These include public agencies, private sector firms, community organizations, TGAs, CBOs and NGOs, social investors, development partners, transporters and traders of forest products, financing institutions, providers of inputs and services, the media, forest users/groups, politicians, and other forest land users.
- Secondary forest production is dominated by private sector that include saw millers, manufacturers of reconstituted wood, charcoal, furniture, non-timber product, wooden transmission poles, paper and paper products.
- In the region the secondary production and manufacturing sectors face numerous challenges ranging from inadequate round wood supplies, inefficient technologies for better conversion, high transaction costs, lack of specialized skills, high cost of credit facilities, inadequate transport infrastructure and unfavourable policy and legal environment.
- In the regional technical and organizational still at infancy stages and is dominated by farm forest producers with grassroots and apex associations that need support to transform into united and more vibrant associations that will serve members better in lobbying for better policies and legal environment.
- The secondary production is dominated by saw milling associations that draws it membership from saw millers. Others include furniture makers, wood carvers and wooden pole preservers associations.

- The links between primary and secondary forest producers in the region is weak and need good will from the government and development partners to foster stronger linkage to enable them reinforce each other and have unified approach in engaging governments.
- In the region most countries have made strides in policy and legislation to empower women and vulnerable groups in ownership, access and management of land and natural resources. However, the good policies and laws are hindered by strong cultural and traditional norms that many communities still have in relation to land and associated resources such forests.
- The countries in the region especially Kenya, Uganda and Tanzania have put in place favourable policies and legislation to support PPPs investment in the forest sector.
- In Sudan inadequate policies and laws on PPP have restricted participation to individuals and village groups that are covered by PFM mostly in joint forest management operations.
- The variants of PPPs in the region range from joint forest management projects between public agencies and various investors and actors whose instruments of engagement include leasehold arrangements, out grower schemes, crop sharing contracts, market linkages and joint forest management.
- The most attractive PPP models to private sector players in the region is the public forestland concessions for establishment of forest plantations but there are no such projects for lack of supporting legislative framework.
- The forest sector in the region has potential to significantly contribute to the national economy and social development through job creation and income generation if some few handicaps are adequately addressed.

Recommendations

- The information on forest production is imprecise estimations and need for comprehensive inventory and data collection to provide critical information to guide forestry policy.
- More focused research on production, consumption, wood-based trade and overall contribution of forestry to rural livelihood and the country's economy is needed.
- The forest sector actors are poorly organized and need some support in terms of capacity building and facilitation to enable them deliver services to their members and front a unified voice to government and other stakeholders on their needs.
- Production and consumption trends indicate increasing deficits in all production lines hence the need for increased investment to enhance primary and secondary forest productivity, increased value addition and efficient infrastructure to serve both local and export markets.
- The public forest plantation sector in Kenya, Rwanda and Sudan are still largely under the public sector agencies and urgent for opening up to private sector investors on concession and lease agreements to inject more professionalism to enhance competition for greater productivity.

- The secondary processing sectors reconstituted wood industries and furniture making need support to consolidate their businesses, upgrade their technologies and improve their operational management to achieve competitive operational scale for increased quality and quantities of products.
- In Sudan, the forest sector need some policy and legal reforms to motivate land owners, investors and workers to participate rehabilitation and management of forest degraded resources.
- Public agencies with mandate on coordinating management of forest resources need to provide support to NTFP producers through capacity building of its members in production, value addition and marketing operations.
- The furniture sector is currently dominated by artisanal operators need government facilitation to through financing and capacity building on modern mass production, upgrading equipment and machinery for large-scale manufacturing to increase overall outputs, productivity, sales, exports, and value addition.
- Given the vast market opportunities in the Eastern Africa furniture manufacturers should position themselves to capture local market share relative to overseas furniture producers.
- Policy and legal reforms to facilitate the growth of the private sector on primary and secondary production for faster pace in forestry sector development in the region.

Acknowledgement
Authors would like to acknowledge the African Forest Forum that supported the study through funding from Swedish International Development Agency (sida). Special thanks to Godwin Kowero, Executive Secretary and Doris Mutta the Project Officer for their useful contribution to the development of the paper and the various persons and organizations for providing data and other support accorded.

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Public Private Partnerships in Forestry Sector Development in Kenya: Synthesis of Status and Potentials

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Abstract

The objective of the study was to evaluate the potential roles of the private sector in development of the forestry sector in Kenya. The categories of forests are public plantations, farm forests, community forests and private forests. Public natural forests are primarily managed for watershed protection and biodiversity conservation. The estimated sizes indicate that community forests mostly in ASALs stand at 24,510,000 hectares, farm and private forests in agricultural landscapes at 10,385,000 and public forests 3,467,000 hectares and public forest plantations accounting for 135,000 hectares. Public and community forests have experienced decline in both coverage and quality as compared to farm and private forests that realized increases. Kenya Forest Service is the key public agency in management and protection of public forests. The private sector players in primary forest production include tea estates, social entrepreneurs, investment syndicates and individual investors that are largely driven by returns to investment or profit motives. The secondary production mostly sawmilling, reconstituted wood manufacturing, utility pole manufacturing, charcoal production, wood carving, paper and paper product manufacturing, biomass energy and non-timber production are dominated by private players. The technical and management organization structures in place include partnerships/contracts between tree growers and companies or social investors, tree growers associations and manufacturers associations most still at infancy stages. The country has put in place policies and legislations to support PPPs implementation in the forest sector that include multi-sectoral PPP policy 2013, PPP Act of 2013, draft National Forest Policy 2016 and Forest Conservation and Management Act 2016.

Keywords: Public Private Partnerships, Public and community forests, Forest Conservation and Management Act, Forestry in Kenya

Introduction

In Kenya the private sector participation in primary forest production as an organized entity is at infancy stages and needs to be nurtured in order to enhance its contribution to development of the forest sector. Private sector players have to be organized from the many diverse actors who largely operate informally to better coordinate their roles in forestry sector development. The private sector players of interests include diversified groups of individuals including young men and women, and marginalized/disadvantaged/vulnerable groups that are dependent on forest sector resources for their livelihoods. To facilitate such development demands the requires identification and understanding of interactions between the different groups of people and the forest resources as well as their differing needs, privileges, contributions, challenges and priorities. However, information on the various categories of players with interest in forest sector and their contributions to the local economy are limited. The private sector development will play greater role in poverty alleviation, and significant impact on women and other marginalised groups. Hence disaggregated data and analysis is crucial in helping to fill the information gap. African Forest Forum with support from donor partners commissioned a national in Kenya to identify key actors in both primary and secondary forestry production. The purpose of this study was is to facilitate development of an organized private sector in forestry, and include identification and promotion of promising public private partnership (PPP) models/approaches for an all-inclusive forest compatible sustainable livelihoods development, including gender considerations.

Objectives of the Study

The main objective of the study was to provide information to support catalysing the emergence of organized private sector in forestry through promotion of promising public private partnership (PPP) approaches for sustainable forest management and enhanced livelihoods including gender considerations.

Methodology

The study relied on information and data that were already available in literature that covered various aspect of forestry in the country. The information accessed were on forest types, primary and secondary production, technology adoption, key actors, forest types, tree species preferences, types of timber and non-timber forest products, recovery efficiency, potentials opportunities for public private partnerships in the forest sector in Kenya. Projections of supply and demand of key forest products in the country for the next 5 years were also covered. The literature consulted includes publications by public agencies, donor projects reports, technical papers, local and international academic papers and NGOs reports.

Stakeholders' consultations

The study consulted experts in various fields of forestry and practitioners mostly through one to one discussions. The consultation process was guided by simple questionnaire and checklist of issues. Those contacted include; KFS officers, saw millers or their agents, tree growers, wooden pole manufacturers, woodworks sector operators, and researchers. The stakeholders were consulted through visits, emails and phone discussions.

Visits

The study involved visits to offices, sites, libraries, farms, factories, timber yards, and furniture making sheds. The visits yielded some critical information that supported various aspects of the study. The study team visited coastal region that included KOMAZA, Kilindini Port, KFS offices (Mombasa, Kwale and Kilifi), Bamburi-Haller Park and South Coast Tree Growers Cooperative Society. In Rift Valley the team visited several transmission wooden pole treatment plants, KFS offices (Kericho, Uasin Gishu and Keiyo-Marakwet), three saw mills, Power saw operators, FOMAWA and Homalime Ltd. The urban centres visited in western Kenya were Kisumu, Eldoret, Busia and Kisii; and in Central and Eastern Kenya they were Nairobi, Nyeri, Muranga, Kitui, Embu, Meru, Machakos and Kibwezi.

Data analysis

The data and information collected from various sources were organized and those relevant to the study were picked and used in various sections of the report. These include recent work on forecast modelling and estimation of supply and demand for various forest products in the country.

Limitations of the Study

The major limitation of the study was unavailability of recent data in some areas. The information on gender and vulnerable groups were also inadequate. Many private forest based enterprises were unwilling to provide information on their activities and the study relied on secondary information in such cases where available. Therefore, the study results are indicative of the true situations. In some cases, expert estimates were used in absence of accurate information.

Results of the Study

The actors in forest sector

The typology of forest sector actors, their mandates and objectives, current management levels and potential for public private partnership are presented in Table 1. The table indicates that public private partnerships in primary production, except for public plantations, are rated low to medium due to scale and complexities involved on property ownerships that may not be attractive to private investors. The rating for manufacturing sector is low due to dominance of private sector investors with minimal public sector participation except in policy and regulatory roles.

Table 1. Typology of the forest sector actors

Sectors	Key players	Management objectives
Primary production		
Public natural forests	KFS, KWS, communities, private sector	Biodiversity conservation
Public plantations	KFS, counties, licensed companies, CFAs	Commercial timber production
Farm Forests	Farmers, schools, social investors	Subsistence and commercial
Community forests	Community groups, counties, individuals	Conservation, subsistence and commercial
Private forests	Tea estates, investment syndicates, large scale farmers	Commercial timber production for own use and surplus for same
Secondary processing		
Saw milling	Individuals, companies	Commercial business
Wooden utility pole manufacturing	Individuals, companies	Commercial business
Reconstituted wood manufacturing	Wood based complexes,	Commercial business
Non timber products	Individuals, Social investors,	Subsistence and commercial
Woodwork sector	Manufacturers and traders ,	Commercial business
Forest products trade	Merchants	Commercial
Research and education	KEFRI, ICRAF, EAWLS, IUCN, NMK and universities	Capacity building, technology development and information dissemination

Source: Own surveys and experiences in the sector

Primary forest production organization

Primary forest production

Primary forest production in the country takes place in public plantations, farm forests, community forests and private forests. Community forests and woodlands are natural forests dominated by indigenous species that are not specifically managed for commercial production but are key sources of firewood, charcoal, timber and poles for local use and surplus for sale to urban areas. Community forests are largely located in the Arid and Semi-Arid Lands (ASALs) of the country. The public natural forests are scattered in medium and high rainfall of Western, Rift Valley, Central and coastal regions. Natural forests host indigenous trees species and animals, and public policy and laws are meant for their protection, and not for production purposes, though illegal harvesting of forest products often takes place in them. Public, private and farm forests plantations provide sustainable supplies of round wood for subsistence and commercial purposes. Species distribution in the country is dictated by climatic and utility preferences, among others values, by both public and private investors. Public plantations located in high potential areas are dominated by industrial species of

Eucalyptus grandis, *E. saligna*, *Pinus patula* and *Cupresssus lusitanica.* On farms woodlots and trees are based on history and climatic conditions, though similar to public plantations, but in most cases take some regional dominance; with Coastal region being dominated by *Casuarina equisetifolia*, *Gmelina arborea*, *Tectonia grandis,* and *E. camaldulensis, E. tereticornis* and *E. europhylla*. In Central Kenya the dominant species are *Grevillea robusta*, *Cupresssus lusitanica*, *Acacia mearnsii* and *E. grandis,* with the latter gaining popularity due to the high demand for transmission poles and its various products. The private sector players, that include tea estates and wood based industries and individual investors, prefer *Eucalyptus grandis* for commercial pole production and firewood for textile and food manufacturing processes but some of the investors have lately diversified into growing *Cupresssus lusitanica* and *Pinus patula*, among other species, for timber production for own use and surplus for sale. Rotation periods for planted trees range from 5 to 30 years depending on species, climatic conditions, end uses and market niche specifications. The country's wood consumption is estimated at 41 million m^3 annually of which 32 million m^3 are used as fuelwood that comprises firewood and charcoal. The balance of 6 million cubic metres is used in production of sawn wood for construction and woodworks, pulp and paper, plywood and wood carvings. The country's per capita consumption is estimated at one cubic metre of wood (MENR, 2013).

Table 2 shows that from 1990 to 2010 selected forest categories experienced mixed performance in terms of forest cover change with the overall change being positive. The key categories that experienced decline were bushlands, indigenous closed forests and public plantation forests in that order. Those that had a positive increase are trees on farms, and private plantations that currently are exhibiting resurgent growth fueled by high demand for its various products that include transmission poles, sawn wood, wood fuel and construction poles. The smallholder and large scale farming actors have diversified their portfolio to tree growing as a commercial enterprise but the latter rapid expansion will come under strain from competition from settlements and agricultural activities hence the pace is likely to slow down.

Table 2. Forest and tree cover (ha) trends in Kenya: 1990-2010

Forest type	1990	2000	2005	2010	Change (%)
Indigenous closed forests	1,240,000	1,190,000	1,165,000	1,140,000	-5
Indigenous mangroves	80,000	80,000	80,000	80,000	0
Open woodlands	2,150,000	2,100,000	2,075,000	2,050,000	-5
Public plantation forests	170,000	134,000	119,000	107,000	-3.15
Private plantations	68,000	78,000	83,000	90,000	+1.1
Subtotal	3,708,000	3,582,000	2,357,000	3,467,000	-12.05
Bushland	24,800,000	24,635,000	24,570,000	24,510,000	-14.5
Farms with Trees	9,420,000	10,020,000	10,320,000	10,385,000	+48.25
Total	41,636,000	41,819,000	40,769,000	41,829,000	+5.93

Sources: FAO 2010: Forest Resources Assessment Report

Public Forests

Natural forests

The natural closed forests measure approximately 1.4 million hectares that consist of various forest types, mostly montane, humid lowland, coastal, mist montane and riverine forests. The montane forests include Aberdares, Mt Kenya, Mt Elgon, Cherang'any and Mau forests. These are forests that are located between 1,800-3,500 m and receive rainfall of between 940 to 3,220 mm per annum. Due to high altitudes the forests are always covered with cloud and mist that provide additional moisture. Montane forests are key water towers in the country. These forests form the largest forested blocks of recent volcanic origin and have relatively few species. The most widespread montane species associations are the moist Ocotea-Polyscias and drier Podocarpus-Cassipourea forests. Juniperus-Olea associations dominate the upper slopes characterized by volcanic mountains and high ranges that consists of evergreen and deciduous species such as *Calodendrum capense* and *Ekebergia capensis* and the association of the Cassipourea-malosana. The montane forests form the 5 key water towers in the country that most of the major rivers like Tana and Uaso Nyiro in Eastern Kenya and Mara, Nzoia, Yala, and Nyando rivers that drain to key lakes such Nakuru, Turkana, Victoria, Naivasha and Baringo that are also of great tourism attraction. The rivers also provide water for both domestic and industrial purposes to many urban and rural homes, wild game and livestock as well.

The *lowland forests* include the Kakamega Forest that is the only tropical rainforest remnant in Kenya that host a range of indigenous tree species such as Elgon teak, Red stinkwood (*Prunus africana*) and African satinwood (*Zanthoxylum gillettii*), *Aningeria altissima*, *Cordia millensii* and *Entandrophragma angolense*. The forests are reported to host as many as 400 species of flora and fauna that include unique animals such as Hoest´smonkey (*Cercopithecus ihoesti*) and two globally threatened bird species: Turner´s eremomela (*Eremomela turneri*) and Chapins flycatcher (*Muscica palendu*) (Pahkasalo, 2004).

The *coastal lowland mosaic forests* occur mainly in strips bordering rivers and coastlines that include extensive mangroves particularly in Lamu and the mouth of the Tana River. The estuaries that fresh and sea water mix form excellent habitats for mangrove forests. The coastal forests are considered to be the last refuges of an ancient forest mass that covered most of Central Africa between the Atlantic and the Indian Ocean. The area's climate is governed by trade winds, and with annual mean rainfall of about 1200 mm. The tree species composition includes the highly diverse Sterculia-Clorophora-Memecylon, Clorophoro-Strychnatalia and Clorophora-lovoa lowland forests. The coastal forests host diverse wildlife such as the endemic Arabuko-Sokoke's Sokoke scops owl (*Otusireneae*) and Clarke΄s weaver (*Ploceus golandi*). The forests also have endangered and rare animal species such as Golden rumped elephant shrew (*Rhynchocyon chrysopygus*), the Sokoke bushy tailed mongoose (*Bdeogale crassicauda*) and Aders duiker (*Cephalophus adersi*). The coral rag coastal forests are dry and typical species include *Antiaris toxicaria, Milicia excelsa* and *Cussonia zimmermannii*. Also along the coastal belt are the Kaya forests that are relict patches of the once extensive and diverse Zanzibar-Inhambane lowland forests that the Mijikenda people built defensive structures to avoid the attacks of raiding Galla warriors. The Kaya forests were retained as sacred forests and are often on hill tops and act as critical water catchments that support diverse flora including medicinal plants.

Mist mountain forests are found in the isolated hills and mountain ranges that are dated across the ASALs of northern and eastern Kenya. The mist forests include Mt Kulal, Loima Hills, Mt Marsabet, Kyulu Hills, Mathews Range and Loita Hills, among others. Due to high altitude the ranges are always covered by mists that provide water to support unique and diverse ecosystems of flora and fauna. The mist forests provide shelter, food, medicine, cultural sites and critical dry season grazing refuge. The water springs support livestock and settlement in an otherwise dryland, hence are part of the 16 micro water towers in the country. The last group of forests are the *riverine forests* that form narrow belts on the floodplains on the major river systems in the country. For example, the largest river, the Tana River, that originates in Mt Kenya and flows into the Indian Ocean, have belts of evergreen forest that depend on its water, and subsides rapidly, away from the river, with the width ranging approximately 1-3 km on either side of the river (Kaarakka, 1996). Lower Tana River forests have two endemic species namely the Tana River red colobus *Procolobus rufomitratus* and Tana River mangabey (*Cercobus galeritus*) (Sayer *et al*., 1992).

In general, most natural/indigenous forests in Kenyan are under pressure from deforestation, forest fragmentation, forest degradation, and over-exploitation of tree species and the introduction of exotic species (Langat *et al*., 2012). The greatest threats are from clearing for agricultural activities because forestlands are located in high population areas and are good for agricultural production. Apart from the key forest blocks most of the remaining forests in Kenya are highly fragmented and many tree species are inhibited from crossing pollination hence face additional risks of extinction. Deforestation and forest degradation can adversely affect many ecological processes and therefore impacting on the soil-water relationship. The Kakamega Forest for example has suffered from continued overuse for timber, charcoal, firewood, cash crops and clearing for forest plantation establishment. The process is attested by Table 2 that shows that of the three categories of natural forests namely the closed and open canopy indigenous forests and woodlands, stagnated or recorded significant decline from 1990 to 2010.

The only indigenous bamboo species found in Kenya is *Oldeania alpina* formally known as *Yushania alpina* that thrives well between 2,400 and 3,350 metres above sea level mostly in slopes of Mt Kenya, Aberdares, Mt Elgon Cherang'any and Mau Complex where it occupies an estimated 155,821 hectares. On average it is estimated that *O. alpina* life cycle is 40 years before mass flowering and death (Wimbush, 1945) and can produce 3,700-4,000 culms per hectare every three years. Further, an undisturbed crop can carry about 10,000-17,000 stems per hectare with capacity to produce 100 tonnes of air dry weight of culms (Kigomo, 1988). Bamboo is very useful in stabilizing top soils and conservation of water quality and is good for protection of fragile areas such as steep slopes and riverine areas. The challenges facing *O. alpina* in Kenya is human induced degradation mostly wanton harvesting, overgrazing and wild life destruction. The species, in addition to limited ecological range, is also difficult to propagate and this hinders extensive planting on farms.

The public plantation forests

Kenya has a long history of public forest plantations development that emerged after trials of indigenous species realized low growth rates in the early 1900s. By 1902 trials of exotic Eucalyptus, Pines and Cypress that heavily borrowed experiences from South Africa and Australia (Gibson, 1965) were established. The objectives for establishment of industrial plantations were to provide wood raw material for specialized industries such as sawmills. By 1986 172,000 ha had been established and an annual planting of 8,600 ha was being undertaken (Cheboiwo, 2007). Massive excisions of plantation forests in 2000s led to loss of 35,000 ha to settlements and by 2010 the public forest plantations covered between 125,000-135,000 hectares accounting for 6% of total forest area managed by KFS. The key species are Cypress (52%), Pines (35%), Eucalyptus (12%) and mixed species (11%). At its peak in 1980s the plantation forest sector supported over 400 saw mills that created 50,000 direct employment and another 300,000 indirectly that excludes downstream woodworks sectors that created further employment in value additions.

The forest sector reforms that began in 1990s culminated in the formulation of Forest Act 2005 that resulted in the formation of KFS as a semi-autonomous organization with the mandate to professionally manage public forests and guide the forest sector in the country. An inventory done in 2009 shows that there were 38,000 hectares of over-mature forest industrial plantation valued at over KES 38 billion (USD 450 million) and another 18,000 ha of between ages 10 and 22 years due for commercial thinnings (Wasike, 2010). However, since the lifting of the ban on harvesting in public plantations in 2012, accelerated harvesting of mature stands has changed the age composition drastically. The KFS has set annual planting target of 3,000 hectares per year and plans to engage private sector stakeholders through concessions, contracting and joint management to boost plantation development in public forests. Recent studies show that the average aggregated yields for key commercial species are as follows *Cupressus lusitanica*, *Pinus patula* and *Eucalyptus grandis* 385 m^3, 401

m^3 and 503 m^3 per hectare respectively (MENR, 2013). The yields are relatively low as compared to private sector production within similar ecological zones that range from 630-750 m^3/ha hence potential room for yield improvements through enhanced silvicultural management and integrated harvesting techniques.

Farm Forests

Table 2 shows that since 1990 trees on farms expanded considerably, by 48.12% to 10,385,000 ha in 2010 as compared to marginal increase of 1.1% for private forests and a decline of 3.5% for public plantations forests. The trend attests to the growing importance of farm forests in forest sector timber production in the country. Some past reports show that in Central Kenya densities of trees on farms averaged 76 stems per ha (Tyndall, 1996*)*, and can host up to 155-200 different tree species (Betser *et al*., 2000; Oginosako *et al*., 2006). The species density vary according the land potential, high potential zones recorded 155 timber trees as compared to 77 in lower cotton zones. The studies showed that twice as many trees are sold per household as felled for domestic use (Holding *et al*., 2006). Indigenous trees found on farms were *Cordia abyssinica, Vitex keniensis* and *Prunus africana*. The Mount Kenya East Pilot Project (MKEPP) (2008) found that in Central Kenya households around Mt Kenya utilized trees on farms for various purposes such as for firewood (93%), fruits (79%), timber (78%), poles (64%) charcoal (43%), fodder (28%), herbs (20%), amenity (8%) and honey (5%). The report also noted that most of the harvested materials were from "standing wood stock" with minimal evidence of replacement indicating that the practices may be unsustainable. Some of the factors that motivate smallholder farmers to grow trees on farms include high population that creates demand for own use supplies of tree materials and surplus for sale, land size, forest incomes, market access and alternative incomes (Cheboiwo, 2014). In general farm forestry in large land holdings is on the increase due to high demand for transmission poles and sawn wood that has motivated medium and large scale farmers to diversify into commercial forest enterprises. However, the smallholder farm forest sector is faced with many challenges that include small farm sizes, conflicts with neighbours over crop losses, felling restriction during crop growing seasons and permits requirement for harvesting and movement of tree products (Oeba *et al.*, 2014). Furthermore, land available for tree growing within agricultural landscapes in high and medium potential zones is likely to decrease given the already decreasing landholding sizes and competition from agriculture, infrastructural development and settlements. Despite the challenges farm forests have performed well in all aspects especially during the period of the sawlog harvesting ban in public forests that lasted from 2002 to 2012 when it became the major source of both subsistence and commercial forest products in the country. The farm forestry will remain an important component of the forestry sector in the country in the future.

Private Forests

The sector in the past was dominated by tea estates owned by multinationals and local companies that planted mostly Eucalyptus for tea curing to substitute expensive furnace oil. However, inability of the public forest plantations to meet local timber needs has attracted several investors into the forest sector that include leading wood based companies, syndicated private investors and large scale farmers that are motivated by lucrative business in tree-based enterprises. The recent expanded electricity power generation and distribution in the country has created high demand for transmission poles, mostly sourced from *Eucalyptus grandis* trees, making it one of the leading short rotation crops grown by private investors and mostly for commercial purposes. The private sector investors deploy broader wood utilization models that include integrated utilization processing and value addition to minimize wastage and improve their operating profit margins. This is because private sector investors are driven largely by profit making hence centred on deployment of efficient management and modern processing technologies. The business model is largely a diversification strategy from a predominantly core agricultural based business into a profitable forest business that takes both vertical and horizontal integration dimensions depending on the core business of the investor.

Though the private plantations expanded marginally by 1.1% from 68,000 to 90,000 hectares between 1990-2010 (Figure1) and lately large companies purchase of huge tracts of land for tree growing the sector has limited room for expansion due to shortage of land and competition from agricultural enterprises and settlements. However, all indicators show that private sector forests are here to stay and will leverage on efficiency in land use, efficient technologies and high demand for forest products to compete in local and regional timber markets. The private sector players are also gearing for the potential opening up of public plantations for forestland concessions under PPP provisions outlined in the proposed National Forest Policy 2015 and National Forest Conservation and Management Bill 2015. Some of the private sector players include James Finlay Tea Estate with 3,000 hectares under forests mostly with *E. grandis* and hybrids of Eucalyptus. Others include Timsales Company Limited 1,500 hectares and Homa Lime Company (280 ha). Some of the private sector firms are involved in forest conservation and out grower schemes with land owners who sell wood to them such as Homa Lime Ltd.

Bamboo growing

The country has embarked on rigorous bamboo production on farms through introduction of eight lowland Asiatic bamboo species as part the country's mix options to diversify the supply base of natural forest resources. Some robust measures to promote expansion of bamboo growing that include awareness creation on its importance, building capacity on propagation and nursery management, training on product harvesting and processing. Some nascent investors on nursery production, commercial growing and processing have started in earnest in various parts of the country. However, there are some outstanding issues that are yet to be addressed that include rigorous evaluation of economic potential contribution to household livelihoods through some cost benefits analysis of bamboo enterprises, guidelines on commercialization of bamboo, and development of efficient market value chains to support a vibrant bamboo sector in the country.

Secondary Forestry Processing

The secondary forestry production involves any alteration of wood harvested from the forest into forms for direct use or transfer to market outlets. Primary processing facilities include sawmills, veneer plants, plywood plants, chipping facilities, pulp and board facilities, utility pole treatment plants, firewood processers, woody biomass energy producers, fuel pellet producers, handcraft makers, furniture manufacturing, shake and shingle operations, among others.

Sawmilling industry

The sawmilling industry in Kenya is one of the most developed in the region having evolved for 80 years, and by 2016 there were 663 registered sawmills operating in the country all owned by private sector entities. The saw milling sector is the largest primary wood processing undertaking in the country that deploys a wide range of equipment from simple machines that include power saws and bench saws to saw mills equipped with gang or band saws and woodmizers. The saw milling operations annual output per saw mill is estimated at 450 $m^{3,}$ and combined production by 2010 was estimated at 400,000 m^3 per year (EPZ, 2010). The saw milling sector is estimated to employ 50,000 workers directly and indirectly providing employment to about 300, 000 people in forest and wood processing operations, as well as in transportation and other supporting services. The public plantations development mismanagement in 1990s led to the sawlog harvesting ban that lasted a decade between 2002 and 2012 resulting in the collapse of saw milling sector and loss of associated skills. During the ban, most saw milling machinery and equipment were left idle and economies of forest dependent urban centres and families collapsed. The lifting of the ban in 2012 has not reignited the vibrancy in the sector for most of the machines left idle are obsolete and need fresh investments in new and efficient machinery. Among the 633 registered mills consisted of 30 large mills, 65 medium, and 538 small saw mills (Cheboiwo, 2012). The lifting of the ban in 2012 released 38,000 hectares of over-mature plantations worth KES 36 billion and another 18,000 ha ready for commercial thinning (Wasike, 2010). The softwood logging plan prepared by KFS indicates that up to 6,000 hectares per year will be available for logging that translates to roundwood output of between 2.4-2.8 million m^3 per year.

In a competitive forestry sector, raw material recovery is critical for it determines the profitability that will have some knock on effects on tree owner's incomes, labour wages, recouping of investment in technologies, and retail timber prices for consumers. Muthike *et al* (2009) reported that due to different saw blades and sawing methods employed, the recovery rates for the 5 alternative sawing techniques were: power saw (27%), tractor mounted circular saw (29.8%), two man pit sawing (39.9%), saw mill equipped with circular saw (40.1%) and saw mill equipped with band saw (46.1%). The pit sawing was the best sawing model for manual sawing operations and bandsaw sawing were the best for mechanical timber conversion. Muthike *et al* (2013) report observed that most of the saw milling managers and staff had inadequate skills in saw milling operations and machine maintenance hence the low conversion rates that averaged 30% as compared to KFS recommended 40% the wastes 70% of the harvested wood.

In summary, the country has sufficient installed capacity of saw milling facilities to produce enough timber to meet the country's needs and surplus for export only when provided with sufficient roundwood. The problem is on the status of the saw milling machinery that have been out of use since 1999 that may need to be addressed to ensure that the sector deploys state of the art machinery for integrated efficient conversion and high recovery rates.

Reconstituted wood products
The reconstituted wood sector is dominated by three privately owned industrial complexes, the Rai Ply, Comply, and Timsales that are involved in integrated wood processing that range from saw milling to plywood and particle boards manufacturing. The board manufacturing units consume about 200,000–250,000m³ of round wood annually (MF&W & MFA 2008). Timsales at Elburgon for example produces soft and hard fibreboards with an estimated capacity of 7,000 tonnes per year. Rai Ply at Eldoret primarily produces plywood, particle and chip boards but has diversified into manufacturing of foam and polythene bags for local and export markets. Comply at Nakuru and Njoro produces medium density fibreboards (MDF) and various particle and chipboards. The complexes have also diversified to manufacturing of plywood, doors, block boards, veneer blockboard, hardboards, chipboard, melamine, machined timber, veneer plywood, creosote transmission poles, flooring tiles and blocks, HDF laminated flooring, MDF, formica, kitchen, wardrobes and office furniture. Furniture includes objects such as tables, chairs, beds, desks, dressers, or cupboards, sofa sets that are usually kept in a house or other building to make it suitable or comfortable for living or working. The complexes have also expanded their operations beyond Kenya into neighbouring countries to widen their operations and access more material base.

Furniture and Joinery
The sector covers such activities as furniture and wooden interior fittings, mouldings, doors, staircases or windows and are spread across the major urban centres in the country. The sector supports about 160,000 people in the forestry and manufacturing sectors of the economy. It is a highly diversified with different types of machines, ranging from imported to locally fabricated wood lathes, bench/handsaws and clamps, among other tools and equipment. The sector is dynamic and its products are mostly for local markets and limited exports. The sector is more of cottage industry than a manufacturing sector for lack standardized products and most is self-employed or with 5-10 employees. Most survive on hard work and ingenious use of resources and form a critical sector in country's economic growth.

The woodworks sector is dominated by small entrepreneurs medium and large firms are experiencing declining production capacity due to lack of quality grade timber, high timber prices, high power costs and high cost of imported chemicals. However, there are some very specialized small scale furniture manufacturing firms that target prime upper class markets that have managed to thrive in the market due to their ability to produce high quality products that have won them confidence of reliable clientele.

World Bank (2014) indicate that the furniture sales in 2013 was approximately US$ 496 million with an annual growth rate of 10% for 2007-2013 that is likely to maintain in the coming years. The report indicates that imports into the country in 2013 was KES 6.6 billion (US$ 66 million) approximately 13% of the total market but imports grew by 24% during 2009-2013 period indicating it will take up a large portion of the Kenyan market in the coming years. The annual furniture sector exports stood at KES 2.2 billion (US$ 22 million) (World Bank, 2015). The demand for furniture in the country is driven by rapid urbanization and increasing purchasing power. The study also estimates that the East African furniture market is valued at US$ 1.2 billion whereas the regional trade is worth paltry US$ 298 million per year. Further, the report notes that the country's furniture industry is better placed to expand its sales domestically and regionally to capitalize on the growing demand in local and regional markets in East Africa, African and global markets due its advantageous geographic position, supply of raw materials from neighbouring and countries that is relatively accessible, and a large workforce with a strong tradition of working in both the informal and formal segments of the furniture value chain.

The furniture is projected to grow at an 8% compound annual growth rate (CAGR) between 2013 and 2018, driven by the growing population, urbanization, and increasing purchasing power. Therefore, the sector mat needs reforms to address quantity and quality material supplies, appropriate technologies, skilled manpower and incentives to attract investments. The woodwork sector is estimated to consume 77,672 m^3 of timber per year (Githiomi, 2010).

Russ rafters' production

There are only two firms that make prefabricated trusses in the country, both located in Nairobi; The Trussed Rafters Development Unit (TRDU) of the Ministry responsible for housing located off Ngong Road was one of the firms. It is equipped with simple industrialized set of truss fabrication jigs, fabricated hand nailed metal plates and conventional woodworking machines. The second firm that makes prefabricated trusses is Harry Timber Engineering Services Limited (H-TES), located along the Mombasa Road. The prefabricated roof trusses are light in weight and are made from well-seasoned grade timber. Truss rafters according to contractors are gaining popularity in the construction industry due to savings in timber and will be a sector to watch with the changing construction styles and technologies in the country. The sector is likely to attract more investments since sawlog harvesting has resumed in public plantations hence availability of high grade softwood timber that had beset the sector for the last decade due to the logging ban.

Prefabricated housing

There are two major manufacturers of fabricated housing units in the country, the Economic Housing Group (EHG) of Naivasha and Timsales of Elburgon. The demand for prefabricated houses in the country has not grown for many years for various reasons that are unique to housing preference in the country that is skewed towards brick and stone houses. Cited also is the high cost of construction due shortage of high grade timber and increasing timber costs and use. The two manufacturers make units on orders and thus experience limited capacity utilization and fluctuations. The units are made from well-seasoned good gauge softwood timber, mostly of pines and cypress.

Wooden Transmission Pole Sector

Primary production of poles

The traditional producers of the wooden transmission poles in Kenya have for a long time been the Kenya Forest Service but the high demand for wooden transmission poles since 1999 has shifted supply to new players, mostly farmers, private companies and importers. The new producers have benefited from access to improved germplasm and plantation management practices for *E. grandis* for high potential growing areas and hybrid clones for medium potential growing areas. The rotation of transmission poles has shortened to 6-10 years and relatively higher for less favourable growing sites. The recommended spacing ranges from 2.5 m x 2.5 m to 3 m x 3 m and with an initial stock of 1,650 and 1,100 trees respectively. Smallholder farmers in most cases intercrop the trees with maize for the first year and singling individual trees for harvesting on the basis of specification; as compared to clear-felling that is done by conventional large scale commercial growers. The transmission pole sector has attracted many private sector players due to high demand returns due to good prices on offer.

Manufacturing of Wooden Transmission Poles

The use of wooden poles to transmit power lines dates back to incorporation of Kenya Power and Lighting Company in 1922. Two other materials, concrete and steel poles, were used in 1960s in transmission of 66 and 11 KV lines in Nairobi and Mombasa but wooden poles have since then displaced hollow tubular and steel lattice. The sector has recorded the fastest growth within the last two decades for in 2004 there were only 2 treatment plants in the country capable of processing 160,000 power transmission poles per year that rose to over 55 by 2016 with to treat over 2 million poles per year (Cheboiwo, 2016). According to electricity power sector projections the local supply of treated wooden poles stood at 63% in 2008 and was expected to meet the country's demand by 2012. Though country is currently self-sufficient in treated wooden poles but it still imports 20-25% of the requirements from Tanzania and Uganda. The combined demand for poles in 2015 was 480,000 poles that was projected to increase to about one million by 2030. The fast growth in treatment plants has come with a cost of inadequate attention to standard treatment procedures hence pole durability and maintenance in use is reported to have worsened.

The sector is also facing competition from resurgent concrete pole sector that has increased from two in 2013 to 7 in 2015 and output from 20,000 to 150,000 poles during the same period. Despite such massive expansion of processing capacity, local plants face several handicaps that include unpredictability of tendering process by the power utility firms that constrain their precise predictions on the actual quantities demanded on annual basis. Such information facilitates them to accurately predict the desired production volumes to aide their synchronization of the purchase of semi-processed poles and import of treatment chemicals from overseas suppliers.

The power generation in Kenya stand at 1,412 MW (Cheboiwo, 2014). The demand for electricity is expected to grow by 10% annually according to Vision 2030 projections and Ministry of Energy has embarked on massive investment in mixes of geothermal, diesel, coal gas, wind and hydropower and imports from Ethiopia and regional utility firms. This is expected to add up to 5,000 MW by 2025. Thus the demand for transmission poles will be highly correlated to the power generation and transmission that will depend on the availability of funds to finance power generation plants and distribution infrastructure in the country. The wooden transmission poles sector is valued at USD 64 million (KES 6.4 billion) spread across tree growers, logging operations, treatment plants and transportation.

Wood Carving

The history of commercial wood carving in Kenya is traced to a renowned Kamba wood carver Mutisya Munge who acquired the knowledge from the Zaramo carvers while serving as soldier in Tanzania in the Second World War (Choge, 2010). By 1956 the wood carving business was worth USD 1.3 million by 2010 exchange rates. The oldest organized group is the Wamunyu Woodcarving Cooperative Society (WWCS) that was registered in 1965, and currently has 1,200 members and a large showroom and marketing warehouse in Katangi Centre in Machakos County. Others include Ukamba Wood Carving Cooperative Society (UWCCS) in Mombasa town and smaller production units in Malindi in Coast region, Nanyuki, Gikomba in Nairobi, Kitui, Kisii, Nakuru, Nyeri, Ukanda, Kibwezi, Kalawa, Meru and Mililuni. The sector employs approximately 60,000 people that are directly involved in wood carving, and that translated to one million persons indirectly dependent on the trade (Choge, 2002). The distribution of costs according to Choge (2002) were cost of wood (30%), splitting and crosscutting (5%), filing of carvings (8%), sanding (30%), painting (12%) and polishing (15%). In general, the carvers market their products through their marketing societies or brokers or directly to individuals. The middlemen dominate marketing of carving destined for international markets. In the smaller wood carving sites, most woodcarvers are not members of a registered cooperatives society but operate independently.

In the past Kenya was a globally significant producer of woodcarvings generating around US$20 million in exports per year (Cunningham *et al*, 2007). The major market destinations for Kenyan wood carvings are U.S.A., United Kingdom, Sweden and Norway. Currently, the wood carving sector is facing several challenges that include shortage of quality wood, ban on harvesting in natural forests, green consumerisms in western countries, and competition from other countries. Due to the diverse problems the country's export markets shrunk by 75% (Hamilton, 1996), that may likely to have worsened by now. The competition is made more severe by lack of creativity amongst the carvers, where most of them produced similar products thus negatively affecting the pricing of their goods.

The wood carvers prefer specific tree species for carving, with *Dalbergia melanoxylon* being the highest ranked. Other popular species include *Terminalia brownii* (muuku in Kamba); *Afzelia quanzenis* (mahogany in English); *Jacaranda mimosifolia* (Jacaranda); and *Combretum schumannii*. The wood carving species are sourced from a variety of sources mostly from farms, woodlands and public forests and minimal imports from Tanzania. In 1990s the demand for wood for carvings ranged from 800-1,200 tonnes per month, sourced from distances as long as 100 km. The sector needs a complete transformation from traditional into well-structured and financed enterprises that can engage in innovative interventions including bulk importation of high quality logs and establishment of commercial plantations of preferred species to sustain the sector into the future. Given the employment creation and forex earning potential the public sector plantations need to factor the need of the wood carving sector in plantation development in the medium and ASAL regions to produce sustainable supplies of the desired species to support the wood carving enterprises.

The recent development in the sector has made most wood carvers to diversify their livelihoods strategies away from wood carving. Recent study showed wood carvers in Wamunyu that relied on wood carving were 62% as 38% had diversified into agricultural and retail businesses to increase their incomes and also cushion them from adverse fluctuation in sales of carvings.

Paper and Paper Products

The largest pulp and paper mill in the country Pan African Paper Mill at Webuye in western Kenya a subsidiary Birla Company of India used to consume annually about 500,000 m^3 of pulpwood and 250,000 m^3 of firewood, mostly from farms. The firm collapsed in 2009 and was recently acquired by Rai Group that has started the revival of the giant mill. There are other 13 companies operating in the country that use recovered paper to manufacture various paper products that include Chandaria Industries located in Nairobi, and Highland Paper Mill located in Eldoret, and among others.

Other Products

Construction poles

Construction poles are mostly produced from farms from various species such as Eucalyptus, Pines, Cypress and many indigenous species. The poles in the coastal region are mostly harvested from *Casuarina equisitifolia* woodlots and are in high demand for construction and renovation of *makuti* buildings (grass thatched buildings) that are popular with tourists. In Central and Western Kenya construction poles are mostly from Eucalyptus woodlots and in some cases Cypress and Pine thinnings that are mostly used for low value construction works such as scaffolding in high-rise buildings and construction of mud houses and kiosks. Construction poles are bulky and low value end products that tend to be supplied from adjacent areas to consumption centres. The major centres of consumption in the country are Nairobi, Mombasa, Kisumu, Nakuru and Eldoret, among other urban areas. The demand for poles has been on the increase due to vibrant construction activities taking place in many towns that require poles for scaffolding and props. Construction poles also form the bulk of the materials used in expanding slum areas in major towns. According to MEWNR (2013) the annual supply for poles in the country, including construction poles, is estimated at 3,028,907. However, the demand stands at 1,409,482 meaning that there is a surplus of 1,619,482, and that is mostly from farms. In summary the construction pole business in the country is assured of sufficient supply of poles from local sources for some time into the future. It has the advantage of short rotation and in small growing spaces, hence can be accommodated within agricultural landscapes across the country.

Industrial firewood

The key users of industrial firewood in the country are textile, food and chemical processing industries, and recently in generation of electricity. The major supplies of industrial firewood are the smallholder tree growers who are spread across the country. One of the major consumers of industrial firewood is the tea sector which is one of the major agricultural activities that contribute to both GDP and foreign exchange. The tea sector in Kenya consists of the smallholder farmers affiliated to Kenya Tea Growers Agency (KTDA) that has 65 factories that account for 80% of the tea output in the country, and the large scale tea growers who are affiliated to Kenya Tea Growers Association (KTGA) that has 29 factories and accounting for 20% of the tea produced in the country. The KTGA affiliated factories were the first group to realize the cost saving measures of switching from furnace oil to firewood use in tea processing. Firewood use in tea processing has triple benefits because it increases profitability of the sector by cutting costs, saving on foreign exchange and increasing overall incomes to tea growers who also supply firewood to affiliate factories. In 2010 the tea sector demand for firewood stood at 1,592,000 m^3 with an estimated value of KSh 2.2 billion, with KTDA accounting for 60% equivalent to its share of tea output.

The large tea estates are generally self-sufficient in firewood, and only sources small quantities from smallholder trees growers and transmission poles treatment plants. The common source of industrial firewood is the fast growing *E. grandis*, *E. saligna* and *Acacia mearnsii*. To sustain the demand for firewood by KTDA affiliated factories requires that a total of 22,800 hectares of forest plantations be developed in the country with an equivalent annual output value of KES 1.3 billion (Cheboiwo, 2012).To ensure sustainable supply of firewood to its factories KTDA encourages its affiliate factories to establish tree nurseries to provide tree seedlings to farmers at reduced prices in order to enable them grow trees for sale to the factories. On average each KTDA managed factories use between 1,000-2,500m^3 of firewood per month. The tea factories uses about 2.7 m^3 of firewood per ton of tea produced. Thus, the value of firewood used per ton of tea is approximately US$87 (about US$814,320 per year). Table 3 shows some other industries that are dependent on firewood in the country.

Table 3. Consumption of firewood by some key industries in Kenya

Enterprises	**Intake in tonnes**	**Unit price (US$)**	**Total value (US$)**
Rupa Mills	2,000	15	30,000
KenKnit	1,700	16	27,200
Corn Products	18,200	18	327,600
Lessos creameries	4,700	18	84,600
Arkay Industries	600	18	1,080,000
Homalime	14,500	23	333,500
D.EA Ltd	2,700	22	59,400
Menengai Industries	2,700	18	48,600
Njoro canning	7,488	16	119,808
Elites Bread	3456	17	58,752
Bidco Industries	5,000	16	80,000
Pan Paper Mills	250,000	18	4,500,000
Highland Paper Mills	4,000	17	68,000
KTDA tea factories	955,200	18	17,193,600
Pwani Oil	8,200	35	287,000

Source: Cheboiwo and Langat 2014

Wood for steam and gasification in electricity production

Recent developments have diversified electricity generation from traditional water hydros and geothermal infrastructure to use of woody biomass for steam technology and gasification processes. Some wood based industries use firewood to drive steam turbines to produce electricity for their internal use. A private company the Cummings Cogeneration plant at Marigat Baringo County was commissioned to utilize *Prosopis juliflora,* a weedy tree species found in ASALs, to produce 30 MW of power through gasification technology. The biomass energy sector is expanding and woody wastes are likely to have good markets as the country expands its electricity generation through mixes of energy sources with green based technologies being preferred. The Cummings has organized the local communities into producers' associations to supply Prosopis wood to the factory from their own farms and community lands. To produce 30 MW electricity Cummings estimates that it will require 240,000 tonnes of Prosopis wood per year. Cummings own estimate of a potential yield of 12,000 tonnes per hectare might require 12,000 hectares of well stocked Prosopis in the target supply areas.

Charcoal production

Firewood and charcoal production are two important forest activities that account for 94% of roundwood extraction from forests and woodlands in the country. The wood fuel per capita consumption is estimated at 742 Kg/yr, translating into 34.3 million metric tonnes; with firewood share being 15.1 million metric tonnes and charcoal16.5 million metric tonnes (MENR, 2013). These would require 538,000 hectares, of which 298,000 hectares will be for firewood and 240,000 hectares for charcoal production. Most of the charcoal traded in the country is sourced from unsustainable harvesting in ASALs and farm clearing in high agricultural potential areas. In most cases charcoal is produced and consumed within the local areas with surplus being moved to major urban areas such as Nairobi, Kisumu and Mombasa. Sustainable charcoal production model based on *Acacia mearnsii* is an established enterprise in Rift Valley that dates back to 1880s whose other product is wattle bark for tannin production. Currently small-scale farmers are the main suppliers of bark in the country and poles are converted into charcoal by the traditional earth kilns. A well-managed *A. mearnsii* stand growing in a good site has a potential of producing 80 tonnes of firewood per hectare at the age of 9-10 years. According to Cheboiwo and Mugo (2012) charcoal production and marketing is a big business in the rural and urban areas, with an estimated 67 million bags, an equivalent to 2.4 million metric tonnes of charcoal, being traded annually. The estimated annual trade arising from charcoal at current average price of KES 800 per 40 kg bag or USD 200,000 per tonne translates to USD 530 million (Wamugunda, 2014). The report by ESDA (2005) showed the charcoal sector involves 200,000 producers and another 700,000 persons employed in the market value chains that support over 2 million dependents. The charcoal market value chain indicates that producers earn 19.3%, transporters/merchants (48.5%) and vendors (32.2%) of the consumer price (Mugo, 2012). Charcoal production in the country is fast changing with more efforts being put in biomass technologies such as charcoal and saw dust briquetting technologies to compliment tree-based production. The technologies are also changing with entry of private sector players that are investing in high recovery charcoal production technologies. Despite the changes the rural based earth kiln producers still dominate the charcoal production business in the country.

National wood supply and demand net balances

The natural public forests, public plantations, farm forests, private forests and community forests are the key suppliers of round wood for both domestic and industrial uses in the country. Table 4 shows that the country has the capacity to sustainably supply of 31,372,531 m^3 of roundwood as timber (23.5 %), poles (9.7 %), firewood (43.5 %) and charcoal (23.5 %). However, the demand is estimated at 41,700,664 m^3 of roundwood as timber (12.6%), poles (3.8 %), firewood (44.9%) and charcoal (39.2%). Timber and pole production were the only products that marginally exceeded demand, however, wood fuel deficits exceed by 50% of the national supply. That indicates that domestic woodfuel users have to resort to unsustainable sources or deplete growing stocks, which will subsequently lead to considerable deforestation or some in cases use agricultural residues. The deficits indicate that wood product consumers, especially in the construction industry, have to rely on imports, especially of hardwood for furniture making and softwood for construction activities or use of substitutes such as metal and plastics in various construction activities.

Table 4. National supply and demand potentials for key forest products (m^3)

Product	Timber	Poles	Firewood	Charcoal	Total woodfuel	Grand Total
Potential supply	7,363,414	3,028,907	13,654,022	7,358,717	20,980,2009	31,372,531
Potential demand	5,262,624	1,409,482	18,702,748	16,325,810	35,028558	41,700,664
Net balances	2,100,791	1,619,424	(5,048,726)	(8,967,093)	14,048,349)	(10,328,134)

Source: MEWNR, 2013

Non Timber Forest Products

Non timber forest products (NTFPs) consist of a range of products extracted from forests and woodlands that include fruits, leaves, bark, gums and resins, among others, for use in subsistence and trade. Non timber forest products have emerged as critical products that support livelihoods of marginalized communities for income and social benefits. Therefore they are important ingredients in local economies and should be considered in sustainable management of natural resources for the benefit of the current and future generations. The following sections discuss some NTFPs of social and economic importance to household and national economies.

Gums and Resins

Gums and resins are among the most valuable dryland woodland resources to ASAL communities. Gum arabic is obtained from *A. senegal* and *A. seyal* while gum resins such as myrrh are produced from Commiphora species and frankincense from *Boswelia neglecta*. Harvesting of gums and resins is based on labour intensive traditional methods of tapping. Nearly, all gums and resins produced in Kenya are exported in raw form; only small quantities are processed locally into essential oils. The country, on average, exports about 460MT per year that peaked in 2000 to 1,130MT that was valued at USD 2.6 million (Chikamai and Casadei, 2005). Ethiopia, Eritrea, Sudan and Kenya are the leading producers and exporters of frankincense, opoponax and myrrh (Cunningham et al, 2007). The global demand for Gum arabic is about 100,000 MT projected to grow to 150,000 MT by 2020 (Muller and Okoro, 2005). Kenya has the potential to annually produce 3,000 MT of gums and 3,500 MT of resins as compared to the current production levels of 400-500 MT for gum arabic and 1,000MT of gum resins (Luvanda, 2015). At an average export price KES 120 per kilogram the country earns KES 36 million (US$3.6 million) per year. Despite the efforts trade in gums and resins in the country has remained largely an informal business due to various factors that range from non-conducive environment for business, resource supply reliability (availability, quantity and quality) and scattered production units (high assembling costs and small scale operational economies) (Wekesa *et al*., 2013). The country has great potential to produce and trade in gums and resins if some of the constraints are addressed, and these include access to vibrant markets, creation of favourable conditions for producers and traders, and sustainable management of woodland resources.

Prunus Bark

In Kenya, *Prunus africana* is found in the major forest blocks of Aberdares, Mt Kenya, Mt Elgon, Cherang'any Hills, Timboroa, Nandi Forests, Taita Hills, Chyulu Hills, Tugen and Marsabit Hills, Kakamega Forests and the Mau ranges. The Prunus bark products are used in treatment of prostate cancer that is common with ageing population mostly in developed countries, this cancer is also receiving local attention. The Prunus bark is traded in various forms such as dried bark, bark extracts, herbal concoctions, capsules and tonics (Schippmann, 2001). Kenya is listed among the leading countries in planting of *P. Africana;* accounting for 628 hectares out of 878 hectares of plantations found in Africa, with the other 250 hectares located in major bark producing countries mostly in Cameroon (Dawson *et al*., 2000). A recent study in western Kenya (Gachie *et al*., 2014) shows that *Prunus africana* is one of the widely retained or planted indigenous tree species in smallholder farms, and with mean density of 0.8 trees per household. The species is mostly planted for ornamental purposes and medicinal use. In the local markets the bark is sold in various forms such as air-dried bark, ground bark powder and herbal liquid concoctions.

The country has been one of the major exporters of Prunus bark since 1960s mostly in purely unprocessed form, with the only value addition being air-drying. The major buyer was the French company, Prosynthese, a subsidiary of the Fournier Group, manufacturers of the 'Tadenan' tablets; with Kenya supplying 60% of its bark demand (Cheboiwo *et al.*, 2014). The country on average exported between 200 and 250 tonnes of dried bark annually to France between 1995 and 2003 and some of the bark was re-exported to China and USA (Cheboiwo *et al*., 2014). The unit price of dried bark during the period was US$60 per kg that translates to between KES 1.2-1.4 billion (US$14-17 million) annually over the 20-year period of trade in the bark. However, the license of the only exporter was cancelled by the government in 2003 and since then no legal exports have taken place in the country. However, herbal practitioners continue to use the bark for production of various medicinal products for local use. Recently some local beverage companies have developed interest in the bark for blending with several products to enhance their curative values and gain local and international consumer preference. The Prunus bark trade and associated activities are some of the potential green based economic activities that have the potential to generate annual incomes in excess of KES 3 billion (US$ 35 million) to the country's economy. However, the country needs to put in place policies and legal structures to promote planting, sustainable harvesting procedures and appropriate extraction technologies to attract investors into the sector. The legal trade in Prunus products will motive land owners to plant them for commercial purposes, and also to enable them diversify their revenue base and spread farming risks while earning the country much needed foreign exchange.

Sandalwood essential oils

Sandalwood (*Osyris lanceolata*) is a widely distributed species in the rocky areas of drylands in Kenya ranging from Kwale in the Coast, to Pokot in Rift Valley and Marsabit in Eastern Kenya. The wood contains highly valued essential oils by Muslims, Hindus, Buddists and Chinese for its sweet fragrance. In Kenya the sandalwood products are used to treat various ailments but such traditional uses in the past have not adversely impacted on its wild populations. However, recent entry of merchants into the sandalwood business mostly for export to Tanzania and India has led to accelerated exploitation across the country. The harvesting methods involve whole tree uprooting for the roots have higher concentration of the essential oils. The local prices range from KES 10-30 per kilogram as compared to KES 700/kg in international markets. Illegal trade in sandalwood thrives in various parts of the country as evidenced by regular reports from arrest and confiscation across the country. The sandalwood tree received protection through 2007 Presidential Decree and is one of the species cited for protection by Forest Act 2005. To widen control in sandalwood trade in the region and globally Kenya proposed its inclusion under CITES in 2013 COP 16 meeting in Bali, Indonesia. However, recent studies indicate that the two protection instruments have not been sufficient to deter illegal harvesting and trade across the country and hence need for more strategic interventions that take into consideration the interests of the land owners (Ochanda, 2014).

Sandalwood propagation has faced challenges due poor seed germination and saprophytic behaviours that need a host plant to survive its early stages of growth. Many private investors have shown interest in planting commercial plantations but have faced challenges of seedling availability and field survival due to lack of appropriate host plants. Kenya Forestry Research Institute has invested heavily in research activities on propagation methods and production protocols to enhance production of seedlings and commercialization of sandalwood. However, there is no breakthrough for mass production of seedlings and field survival hence more efforts still needed.

Baobab Fruit

Baobab (*Adonsonia digitata*) is an iconic multipurpose tree of the semi-arid and sub-humid zones of sub-Saharan Africa whose leaves, fruit, seeds and trunk provides a variety of uses that include water storage, medicine, oils, and clothes. The production of baobab pulp and leaves is almost entirely sourced from trees growing naturally in woodlands. Baobab products have growing markets in the country, Europe and the US. Therefore, baobab products offer income opportunities to landowners that have baobab trees on their farms. Among local investors in baobab processing is Elekea a Nairobi based SME that has established an integrated baobab processing unit produce O'Bao baobab fruit powder brand that consist of a range of products for the purpose of building an economic business around the baobab resource in Kenya. This is because the presence of baobab trees is increasingly becoming a burden to land owners who do not see any economic benefits hence cases of increased felling of the magnificent tree to make way for conventional agriculture. Elekea by-products include charcoal briquettes and oil seed cake for animal feed. Elekea in collaboration with local research institute has built a network of women groups to harvest, assemble and sell baobab fruits through fair-trade pricing structures to incentivise the farmers to protect the trees.

Tamarind Products

Tamarindus indica commonly known as *Tamarind* tree is one of the most important multipurpose tropical fruit tree species that grows in ASALs and coastal areas of Kenya. Its fruit has been used as a traditional medicine in Asia and Africa for centuries. In Kenya many communities use tamarind fruit to treat many ailments such as abdominal pain, diarrhoea and dysentery, among others, since the fruit is rich in phytochemicals. The plant has potential for commercial utilization in medicinal and pharmacologic activities. Tamarind business revolves around fruit collection in ASAL and transportation to key markets in Mombasa because local market opportunities are limited. In 1999 the price per kilo was KES 3 but in Mombasa it traded at KES 20-60. The country is estimated to have capacity to produce 600-800 tonnes per year (Bester, 1999). Although the export market potential exists in Japan, North America, Europe and Middle East, the country only exports about 1,000 tonnes per year to Somalia and Yemen. The ripe fruit is usually eaten fresh and also made into juice, jam, syrup and candy a practice that can be commercialized by local firms.

Tannins

Tannins from black wattle (*Acacia mearnsii*), originally from Australia is the main source of high quality tannin used internationally in the leather sector. In 1999, South Africa produced 66% of world supply of black wattle tannin extract from its 202,345 hectares under South Africa Wattle Producers Association and Kenya was second with 25,000 tonnes. The winding of East African Wattle and Extract Company (EATEC) in 2000 saw the subdivision of its 10,000 hectares of black wattle estates near Eldoret into smallholder agricultural farms. The exit of EATEC saw the closure of the tannin extract factory in Eldoret, leaving the country with only three factories in Nairobi and Thika that are still being sustained by local bark supplies and imports from Tanzania. The country's leather factories rose from 9 in 2005 to 13 in 2009 with capital investment of KES 3.8 billion (USD 38 million). The leather production rose from 5,000 tonnes in 2003 to 20,000 tonnes in 2007. The turnaround has been largely due to increase on tax levied on raw hide exports from 20% in 2006 to 40% in 2007.The leather factories employed 4,000 people. However, the country's black wattle extract exports fell from 5,340 tonnes in 2002 to 46 tonnes by 2008 due to combination of falling production of bark and increased domestic demand with expanding leather tanning sector that needed up to 10,000 tonnes of tannin per year in 2009. The demand for the tannin in the country is expected to increase with the growth of domestic leather sector and the country may realize shortfall in supply in the next few years if the sector maintains the current declining annual growth.

Aloe Products

Aloes are a group of succulent plant varieties adapted to dryland conditions that have emerged as an important source for production of various medicinal and industrial products. The high value species include *Aloe turkanensis* and *Aloe secundiflora* that contain aloin the highly sought for as a natural ingredient for body lotion and medicinal products. There are two Aloe products processors in the country, namely the Pwani Aloe Processors based in the Coastal region and Baringo Bioenterprise based in Baringo County of Rift Valley. The two processors purchase and process indigenous aloe products for local and export markets. Some research and development by KEFRI has resulted in the publication of technical guidelines on planting, management and harvesting of various aloe species in the drylands. Many individuals, groups and institutions have trial plantations of Aloe of various sizes across the ASALs areas. In 2008 KWS published Aloe Regulation to guide Aloe leaf harvesting and processing in the country. The sector is still in its infancy and is likely to expand its presence in the future due high interest from various investment groups, both at primary and secondary production, targeting growing local and global markets for herbal ingredients and remedies. However, global trade in indigenous Aloe products are regulated under CITES and therefore local producers eyeing international markets have to undertake rigorous management and production procedures that meet the stringent export licensing requirements by KWS.

Technical and Commercial Organization of Forest Production

Technical and commercial organization of forest primary production

Technical and commercial organization in primary production looks at the organization, the structure of the sectors, skills and strategies to enhance primary forest production in key enterprises such as sawlog, poles, firewood and charcoal production. Primary forest resources are normally managed through well-defined management plans that align resources around technical and commercial aspects of the business.

Training, Research and Technical support

In primary production KFS has been the dominant player with well-organized administrative structure and resources to cover the core business of management and protection of public forests and support to private and individual forest owners. Its work force is estimated at over 5,000 with 60% involved in enforcement activities. The recent entry of commercial oriented entities such as the tea estates, social entrepreneurs, investment syndicates and individual investors has changed the primary production landscape into more efficient profit driven business models. The Kenya Forestry College, started in 1957, enrolling students for certificate and diploma in forestry courses that is geared towards skills on practical competence in forest management operations. Graduate level foresters are trained in University of Eldoret and Kenyatta University; Egerton University offer natural resources and environmental science courses whereas University of Kabianga and University of Eldoret offer Agroforestry. The mandate of the Kenya Forestry Research Institute (KEFRI) is to generate and promote improved technologies for sustainable management, conservation and development of forests and allied natural resources. The Institute has played a key role in the identification, selection and promotion of species for various agro-ecological zones in the country for both subsistence and commercial purposes. It also supports training and capacity building in forest management, product processing and pest and disease control, among others. KEFRI has about 1,000 staff comprised of technical and support staff to carry out its various functions.

Investment syndicates forest joint ventures

This is a new set of limited companies that have acquired investment funds from corporate and individual investors locally and overseas, and with interest in green economy and profits from forestry enterprises. Examples include Better Globe Forestry Ltd in eastern drylands and Coast region, Million Tree Project, in western Kenya, and KOMAZA and ASANTE in Kilifi County in the Coast region. The companies have partnered with tree growers under various partnerships that involve signing of contracts between the individual farmers and the respective companies. Under the contract agreements the companies provide seedling and technical services whereas the land owners provide some minimum land for planting trees and woodlot maintenance. The proceeds from sale of the harvested produce are shared between the two entities in agreed ratios after costs are deducted. Some contracts are leasehold type where the investors pay land owners for the use of the land for an agreed period that ranges from between 10 to 30 years, depending on rotation period of the tree crop. The payments also vary from wholesome for contracted period to annual payments. Some contracts are flexible and provide room for contracted tree growers to withdraw from a contract within the contract period by paying stipulated compensation sum to the company for costs incurred. The technical and organizational structures are well structured for the companies for they normally operate as business entities, and with staff with technical and financial expertise to advise the companies and individual tree growers. The trees grown are managed to the highest standards that meet the expectation of the investing company and individual contracted farmers.

Tree Growers Associations

There are two categories of tree grower umbrella groups in the country namely Farm Forestry Smallholder Producers Association of Kenya (FF-SPAK) for smallholders and Kenya Forest Growers Association (KEFGA) for large scale growers.

FF-SPAK smallholder woodlots range from less than 0.025 to 10 hectares for subsistence and commercial purposes. The smallholder tree growers generally are poorly organized because in most cases the individual farmer manages the production systems with minimal professional inputs. The smallholder sector has been target for transformation into better organized producer associations to enhance yields and pricing for their products. Estimates indicate that there about 10,000 tree growing farmers that are members of tree growing associations affiliated to FF-SPAK. The FF-SPAK core business is to mobilize tree growers into networks that can do business including management and administrative capacity building and extension services

The Kenya Forest Growers Association (KEFGA) has a well-structured national office and its members pay registration and annual subscription fees based on size of their forest woodlots, and are categorised into two groups: those with woodlots below 12 hectares and those owning above 12 hectares. KEFGA membership is estimated at 5,000 members and has been in many forestry related forum such as National Forest Management and Conservation 2016 that ensured that the interests of private tree growers was taken care. According to KEFGA its members has added 17,000 hectares of forest cover across the country and created 30,000 new jobs in rural areas. KEFGA members were critical in supplying about 200 saw millers that operated during the ban on harvesting sawlogs in public forests between the 2002-2012 period.

Charcoal producers' associations

Other producer associations operating in the country is the Charcoal Producers Associations (CPAs) which is the outcome of the subsidiary legislation the Forest (Charcoal) Rules 2009. These regulations require that all charcoal producers in the country to become members of a CPA in order to be registered, licensed and qualify for technical support by KFS and county governments. The CPA is an umbrella body to bring together individual charcoal producer groups who control and produce charcoal in a sustainable way in the various parts of the country. Some of the requirement includes registration under the Societies Act, CAP 108, and among the provisions are procedures for election of officials to manage the CPAs and terms of office for elected officials. The CPAs are required to develop management plans for not less 100 hectares, use high recovery technologies, and have a tree nursery with capacity of at least 25,000 seedlings. Several CPAs have been registered with the KFS directorate and their operational status is yet to be evaluated.

Technical and commercial organization in secondary forest production

There are two technical organizations in the secondary production namely Timber Manufacturers Association (TMA) and Kenya Wood Preservers Association (KWPA). The TMA was formed in 1981 to promote the interests of saw millers countrywide. It is a loosely operated entity without clear leadership structure and business operation. The TMA objective is to lobby for timber rights for its members mostly from KFS plantations. At its inception it had 200 active members and now has 300 members on paper as 80% closed their saw mills and are yet to open due to unclear tendering processes. Its members are required by KFS to be tax compliant, and have adequate workers' compensation schemes and payment of a non-refundable KES 30,000 (USD 300) license fee before being considered for pre-qualification. Saw mills, unlike before when they were the dominant players in the public plantation sector, are facing serious competition from large scale integrated wood based industries and hundreds of mobile saw millers spread across the country. During the 10-year ban (2002-2012) on harvesting in public plantations some TMA members relied on farms for sawlogs to keep the mills in operation. On the bright side few large saw millers have started establishing own plantations and are also eyeing the highly anticipated public forest land concessions to grow trees for future supplies. The KWPA is a membership organization that draws the bulk of its members from wood treatment plant owners, suppliers of treatment chemicals and other persons and entities with interest in wood preservation activities. The main objective of

KWPA is to promote the preservation of wood in the country to international standards for longevity in use, convenient to use and attractive to customers. The KWPA aspires to achieve its objectives through implementation of its code of practice by members. It also advocates for proper disposal of chemical waste, increased production capacity of plants and reduction of production costs. Members are required to pay registration fees of KES 100,000 (USD 1,000) and an annual subscription of KES 50,000 (USD 500). It has an office in Nairobi staffed with a wood scientist who handles inspections of plants and offers full-time quality surveillance. The KWPA collaborates with Kenya Bureau of Standards (KEBS) in the development of a code of practice for treatment plants in the country in order to ensure that they meet international standards. It also aims at mobilization its members to negotiate for fair prices for raw materials, chemicals and treated wooden pole materials. It also lobbies the government to provide conducive legal and business friendly environment to enable the sector grow. The KWPA also offers technical assistance to farmers to form groups of polewood growers that use the best management practices to meet the desired specifications and that attract better prices.

Relationships between actors in primary and secondary forest production

In the country there are minimal linkages between primary forest producers and secondary forest production actors. Though the primary sector is the major supplier of materials to the secondary production sectors in most cases each sector operates independent of the other. In some cases, such as KWPA and TMA, the formal structures have some interest in primary production through technical support and price negotiations or participation in tenders for KFS managed plantations the dominant primary sector player. The secondary production sectors in some cases use brokers to source raw materials from farmers through some formal or informal supply contracts. This is largely because farmers don't provide continuous supply of wood but in most cases sell trees in times of need or once after a long period. Past attempts to link tree growers to secondary producers has failed because trees take long time to mature and family dynamics make it difficult to draw and observe contracts that bind tree growers to secondary producers as buyers. Some of the issues that arose on use of contracts to link farmers to industry were high cases of failure due to their non-observance of the agreed terms. Non timber forest products (NTFP) is the least organized sector that includes a wide range of small scale operators such as honey gatherers, herbal medicine collectors, and pastoralists involved in gum and resin collection. The sector is characterized by small scale actors that collect specific non timber products in small quantities from the wild for subsistence or sell to merchants. The non-timber products collected from forests and woodlands in the country include the following: Aloe sap, honey, fruits, grass, gums and resins. For example, in Northern Kenya some attempts have been made to organize gum and resin collectors into loosely networked groups that are trained on improved tapping procedures and linking them to better markets. In public forests under PFM, CFAs in collaboration with KFS regulate collection of non-timber products for own uses.

Trade in Timber and Other Forest Products

Tree products imports from East and Central Africa

Kenya stopped harvesting hardwood from its public indigenous forests in the 1980s and relies on softwood from public forest plantations, farms and community forests. However, the country's construction and woodwork sectors are undergoing rapid growth hence need large quantities of both softwood and hardwood timber to meet the demand occasioned by rapid urbanization. The country has progressively increased its hardwood timber imports from DRC and softwood timber from Tanzania to close the widening gap between local timber production and demands. Hardwood imports from DRC rose steadily from 9,267 m^3 in 2009 to 38,506 m^3 in 2013 and softwood sawn timber from Tanzania peaked at 57,300 m^3 in 2010 but have since fallen to 9,425 m^3 by 2013 (Cheboiwo *et al*., 2015). The value of hardwood import between 2009 and 2013 from both DRC and Tanzania was KES 15.6 billion ($184 million).

International trade in forest products

Kenya, despite being the most industrialized in terms of the number of wood based industries in the region, remains a net importer of various products that include timber, paper and paper products, wood based panels (Table 5). The exports include paper and paper products, wood based panels and pulp and recovered paper. For example in 2014 Kenya imported 47 million metric tonnes (MT) of wood based panels and exported 3.5 million metric tonnes of the same. In the period 2010-2015 the value of imports was US$ 1.8 billion as compared to US$ 350 million worth of exports. The trend in imports, on average, is on an upward trend, whereas exports are on a downward trend; indicating the country's balance of trade in forest products is negative. The collapse of PPM in 2009 translated into massive jump in imports and increased the country's dependence on imported paper and allied products. The exporters of forest products to Kenya include China, South Africa, Malaysia, Tanzania, Turkey, Germany, Thailand, India, USA and Sweden among many others countries. Kenya exports various wood products which include cork, wood carving, paper, and wattle bark extract to different countries mostly in Africa. These include Sudan, Democratic Republic of Congo, Rwanda, South Africa, Uganda, Tanzania, Ethiopia, Cameroon, Zimbabwe and Western Sahara. Kenya also exports to other parts of the world namely Israel, Italy, England, Belgium, Norway and China

Table 5. Export and imports of forest products in Kenya: 2010-2015

Commodity	2010	2011	2012	2013	2014	2015*	Value in US$
Roundwood (m^3):Exports	26,592	80,815	14,921	67,699	5,494,320	235,828	4,281,318,736
Imports (m^3)	498,250	213,771	109,3527	117,202	316,5591	1,897,922	6,200,184
Wood Fuel (MT): Exports	84.9	34.2	24.1	136.5	129.6	56.1	184,455
Imports (MT)	23	75	48	73	9	163	138,493
Sawn wood (MT): Exports	147,050	137,105	101,874	38,755	55,116	34,550	7,347,849
Imports(MT)	112,617	173,782	121,034	103,786	128,700	196,952	1,300,756
Wood based panels: Exports(MT)	12,621,196	14,636,908	10,666,984	10,750,900	10,370,338	5,300,483	134,641,197
Imports	31,901,758	37,254,300	46,315,076	45,896,200	56,298,649	47,040,139	52,031,670
Pulp/recovered paper (MT): Exports	18,626	2,388	6,530	893	11,586	12,094	6,920,106
Imports	2,433	1,629	1,288	1,114	1,480	1,031	101,253
Paper/paperboard (MT): Exports	45,220,274	52,310,413	56,178,002	53,527,093	45,204,168	35,287,459	1,625,574,900
Imports (MT)	301,486	320,126	304,073	306,831	351,998	239,466	290,695,325
Total export value in USD	49,217,776	64,476,491	61,058,594	79,254,997	55,618,725	40,841,099	350,467,683
Total import value in USD	255,215,865	344,315,717	323,905,628	304,345,011	335,802,539	241,336,181	1,817,481,696

Source: National Bureau of Statistics, 2015
*Data up to August 2015

Other Forest Sector Related Issues

Forest sector related policies and legislations

Land use in Kenya is influenced by many factors that include soils, climate, labour, technology and markets. Since land has increasingly become a scarce resource land owners' decision making process on land use choices is, in most cases, influenced by prevailing policy and legal environment through commodity prices and incomes. Therefore, governments always influence land use change towards national desired direction through policies, legislations, and regulations that are crafted to provide incentives to land owners to realize socio-economic and social values. The government has enacted various policies and legislations in order to positively influence investments in primary and secondary forest production by individual land owners, public institutions, private investors and community groups. Some of them include Public Private Partnerships Act, 2013, National Forest Policy 2016 and Forest Management and Conservation Act 2016. The Forest Act 2016 provides conditions for implementing forest concessions, and related management agreements. It obliges the government to fast tract formulation of subsidiary legislation on Forest Concession Framework that confers right to management of public forests to third party players up to a period of 30 years. Under these conditions, the risk and uncertainty borne by investors with interest in entering partnerships with KFS will be mitigated by the terms outlined in concession framework. The Constitution of Kenya 2010 section 69 places some conditions on acquisition of large land and natural resources concessions that include consultative processes and parliamentary approvals. Therefore, PPP Act of 2013 and Forest

Act 2016 provides conducive environment for private sector engagement in long term sustainable forest management practices through various instruments.

Gender and marginalised groups participation

The population of Kenya in 2009 was estimated at 40 million people, and consisting of 43 ethnic groups of which five communities accounted for over 50 per cent of the population. The breakdown of country's population shows that nine ethnic groups had a population that exceeded one million people and 32 were below one million people. Those ethnic groups that had populations of less than 100,000 people were 18 and therefore fall into the category of minorities. Some of these minority groups are hunter-gatherer communities that are dependent on forests resources, and include the Ogiek, Yaaku, the Sengwer, El Molo and Awer, among others. They are facing sustained pressure from neighbouring populous agricultural communities that are hungry for land and are also vulnerable to government eviction from public forests reserves. In most cases the minority communities rely on insecure customary rights in relation to forests and lands in their regions. However, the country's resources are managed through statutory legal systems that are taken into consideration in judicial processes, and hence are likely to deprive minority communities of the decision power on their natural resources(Minority Right , 2012).Although the Kenya Constitution 2010 contains numerous positive provisions for minorities and other vulnerable groups, recent assessments indicate that in general their vulnerability has increased because the capacity and institutional structures on legislative and administrative matters are weak (Songoei, 2012). Minorities are vulnerable to assimilation, displacement, exploitation and even discrimination by powerful communities and land grabbers because of their weak bargaining position in political, policy and legal decision making, which is exacerbated by their low numerical numbers, low education levels, high poverty levels and ignorance of their rights (Songoei, 2012). The structure put place to address the problems facing minorities and other vulnerable groups that include the Constitutional Implementation Commission (CIC), Truth, Justice Reconciliation Commission, (TJRC) and Ombudsman that can join hands with civil society groups and other agents to ensure that the progressive provisions in the Constitution advance the protection of minorities and vulnerable groups for national stability.

Although existing policies and legislations are not primarily discriminatory with regard to women owning land, they have however not provided adequate security of tenure for women, especially where land is administered through customary norms and procedures. World Bank Report (2007) shows women owned only 1.5% of all titled land in the country, and this attests to the property relationship between men and women that is shaped mostly through traditional customs and marital arrangements. This is the case despite the fact that that 30.9% per of households in the country are female-headed (CBS, 2006). In most cases land asset ownership in rural areas is transferred through males in the family tree. Therefore, women currently face natural resource and asset vulnerabilities because their access rights are still dominantly related to kinship and marital relationships. Gender participation in public plantation sector varies according to the operation segment activities. Nursery, planting and maintenance operations provide equal opportunities for youth, men and women but women tend to dominate due to the light duty and gentleness requirements in handling seedlings.

Observations showed women dominate in tree nurseries and forest products market value chains such wholesaling and retailing in both urban and rural areas of such products as firewood, charcoal and NTFPs related SMEs. Thinning, pruning and logging operations are heavy duty activities that are dominated by men due to physical nature of the work and type of machinery and equipment deployed. In general, the minority groups have equal opportunities in primary production activities for there are no significant constraints to their engagement as owners or employees. However, in forestry like many other sectors of the economy, factors like weak political connections and lack financial capacity weakens the ability and capacity of minorities and women groups to participate in key forest sector operations and investment such as obtaining logging licenses and undertaking saw milling activities.

Trends on production, trade and consumption of timber and non-timber products

Forecast on future forest product supply: 2012-2026

A report of The Ministry of Environment, Water and Natural Resources (MEWNR) in 2013 used models based on population and sectoral economic growth, including wood based consumption centres and yield potentials for the various types of forests, to forecast the supply of wood products in Kenya for 2012-2032. The forecasts for key forest products showed that the supply of timber is to grow by 28.8 %, poles by 29.2 %, firewood by 15.3 %, and charcoal by 16.1 % in this period. The overall wood supply was forecasted to increase by 20% from 31,372,530 m^3 to 37,647,850 m^3 for the period (Table 6).

Table 6. National wood products supply projection for 2016-2026 (1000' m^3)

Product	**2012**	**2014**	**2016**	**2018**	**2020**	**2022**	**2024**	**2026**
Timber	7358.45	7550.89	7723.49	7942.39	8117.71	8352.66	8547.92	8777.35
Poles	3029.65	3102.52	3177.29	3265.30	3357.87	3445.37	3535.49	3618.75
Firewood	13639.88	13845.77	14054.78	14254.17	14451.38	14678.82	14875.43	15064.60
Charcoal	7344.55	7454.29	7566.21	7680.33	7792.73	7909.19	8028.06	8152.51
Total	31372.53	31953.47	32521.77	33142.19	33719.69	34386.04	34986.90	35613.21

Source: MEWNR (2013)

Forecast of future forest products demand: 2012-2026

The demand for forest products is highly correlated with the economic development, demographic changes, and competition from competing substitutes in use. According to MEWNR (2013) the demand of timber is projected to increase by 43.2 %, poles (58.2 %), firewood by (16.1 %) and charcoal (17.8 %) by the end of this period. The total wood demand is expected to grow by 21.6 % from 41,700,660 m^3 in to 50,712,100m^3 an increase of 9,011,440m^3 (Table 7). The supply and demand projections clearly indicate that the country will face acute shortages of forest products in the near future, and therefore the needs to intensify productivity in public forest plantations and as well bring on board the private and farm forestry sectors into the national supply of forest products. The nascent private sector and farm forestry are the only potential sectors that may realize some significant growth in both land areas and production given the land and management constraints currently facing the public sector plantation forests.

Table 7. National wood products demand projection for 2016-2026 (1000' m^3)

Product	**2012**	**2014**	**2016**	**2018**	**2020**	**2022**	**2024**	**2026**
Timber	5262.62	5465.05	5674.72	5908.44	6120.67	6356.66	6628.14	6802.66
Poles	1409.48	1473.85	1542.10	1613.93	1692.38	1768.05	1854.65	1932.33
Firewood	18702.75	18936.08	19220.67	19559.70	19860.51	20135.65	20441.91	20749.93
Charcoal	16325.81	16615.39	16851.66	17127.07	17415.41	17737.85	18046.41	18398.90
Total	41700.66	42490.37	43289.15	44209.14	45088.97	45998.21	46971.11	47883.82

Source: MEWNR (2013)

Contribution of private forestry sector to employment and livelihoods

The private forestry sector activities are spread across both primary and secondary productions that include plantation establishment, plantation maintenance, logging, processing, manufacturing and transportation. The manufacturing sectors are crucial in forex saving and earning in cases of exports. The key private forestry activities include sawmilling, wood based manufacturing complexes, furniture making and collection, processing and value addition of non-timber products.

For example, the transmission pole sector is worth KES 6.4 billion shared among many actors in the market value chain with wooden pole tree growers taking 29%, manufacturers-31%, treatment costs-29%, and logging transport-11% (Cheboiwo 2014.) The value of the furniture market in Kenya is estimated at approximately at US$ 496 million (World Bank, 2015). At its peak the wood carving sectors employed between 50,000-60,000 carvers, and generating around US$ 20 million in exports per year (Choge, 2002). Therefore, the diverse private activities create employment opportunities to hundreds of people; generate taxes to governments, interest to financial institutions and profits to investors.

Forest sector contribution to national economy

Kenya's forestry sector contributes 3.6% to the GDP, and is one of the sectors identified by the vision 2030 as critical to sustainable development in the country (UNEP, 2012). The forest employment and income generation opportunities within the forest products market value chains are vast. Enormous opportunities exist in products processing to distribution of key products such as sawlogs, transmission poles, reconstituted wood products, furniture, charcoal, construction and fencing poles, and non-timber forest products. Therefore, forest sector creates employment and income from direct and indirect business opportunities it creates. Forest related businesses provide both direct cash and non-cash economic contributions and substantial levels of employment, both in formal and informal sectors, mostly in SMEs. Table 12 shows estimates of annual consumption of some forest products by some key economic sectors in the country. The value of such consumption is estimated at US$ 785,440,000 (KES 78.5 billion), mostly traced to domestic household energy needs, and therefore indicating the economic importance of the forest sector to the country's economy.

Existing and Promising public private partnership models in forestry

There are some existing and potential PPP models for forestry sector investment in the country that include public forestland concessions, out-grower contract schemes, land lease agreements and combinations of market assurances, technical and financial support. PPP in the forest sector may take longer to implement due to some structural development that may need to be put in place such as the guiding principles that will encourage and sustain out-partnerships. These include building of mutual trust, fair negotiation processes, longer learning curve, and equitable share of benefits and risks. The country has in place some key ingredients that make out-grower schemes attractive and viable such as the inbuilt culture of tree growing among farmers, favourable policies and legislations, many wood based enterprises that can buy various products, efficient marketing and price information systems and a big pool of local and overseas investors in the forest sector businesses.

Despite conceptual appeal and the perceived benefits, the out-grower schemes based on forestry commodities are still new ventures in the country, and with some fundamental issues and experiences having not been tested fully. Some of the key factors that are yet to be fully appreciated include commodity types, technical requirements, cultural aspects, and observation and enforcement of contractual agreements, among others. These are crucial in designing replicable and scalable PPP models in the forestry sector.

Conclusions

- In general, the primary forest production sector concentrated in public, private and community forests are experiencing decline in size and cover through several degradation processes mostly overgrazing, tree cutting, poaching, charcoal production, encroachment by illegal settlers and conversion into other land uses.
- The public plantation forest sector declined from 174,000 ha in 1980s to 125,000 hectares but the farm forests and private sector experienced slight increase over the same period.
- In contrast the demand for various product categories is fast increasing hence need for concerted effort in forest sector development in order to expand production of various forest products in the future.
- The key primary producers include KFS that is mandated to manage public plantation and public natural forests. Other actors in primary forest production include companies, farmers, community groups, investment syndicates/social entrepreneurs and traders, among others.
- The secondary forest production is dominated by private actors that include saw millers, manufacturers of reconstituted wood, charcoal producers, in addition to producers of furniture, non-timber products, wooden transmission poles, paper and paper products.
- Forests also produce a wide range of non-timber forest products that include Gums, resins, opoponax and myrrh, Prunus bark, sandalwood essential oils, Baobab fruit, Tamarind products, tannins, medicinal plant parts and Aloe products, among others.

- The level of investment in processing technologies varies depending on the sectors, actors, and technology requirements dominant being saw milling that varies from the high recovery advanced large scale mills to artisanal power saw and hand saw operators with low recovery rates.
- The reconstituted wood industries and wooden pole treatments plants are other key manufacturing sectors
- The secondary production and manufacturing sectors face numerous challenges ranging from inadequate roundwood supplies, inefficient technologies for better conversion, high transaction costs, lack of specialized skills, high cost of credit facilities, inadequate transport infrastructure and unfavourable policy and legal environment.
- In the country technical and organizational in the primary production are dominated by nascent small-scale tree growers that in some cases are organized into grassroots and apex associations.
- The secondary production is dominated by saw milling association that draws it membership from saw millers. Smaller groups include furniture makes wood carvers and wooden pole preservers association that represents the interests of respective members.
- The links between primary tree growers and secondary producers in the region is still weak because tree growing is perceived to take long time to mature and family dynamics make it difficult to draw and observe contracts that bind tree growers to secondary producers as buyers.
- The country has made strides in enactment of favourable policies and legislations to empower women and vulnerable groups in ownership, access and management of land and natural resources. However, the good policies and laws are hindered by strong cultural and traditional norms held by many communities in relation to land and associated resources such forests.
- Kenya has enacted policies and laws that are supportive to PPPs in the forest sector in order to inject private sector management efficiency and financial resources in both primary and secondary production. The most attractive PPP models to private sector investors include public forestland concessions for establishment of forest plantations. However, there is no concession project in place because the subsidiary legislation framework to support its implementation is not yet in place.
- Some forms of PPPs in operation include linkages between public sector agencies and various actors such as individual tree growers, community forest associations and wood based companies or social entrepreneurs.
- The private sector investors in the forest sector through their diverse production activities create employment and generate income to various players that include employees, input suppliers, financial service providers, taxes to government and its agencies and forex exchange.
- The economic sectors that are dependent on wood based products such as saw milling, construction, transmission utilities, pulp and paper industries and furniture makers, among other sectors needs high materials inputs from primary production sectors.
- Public plantation forests, private forests and farm forests are under pressure to producer more roundwood to meet the increasing diverse forest products demands from various sectors of the economy as a result of rapid expansion of population and urban areas.

- To meet the deficits in local production some the country imports wide variety of wood based products that include sawn wood, knock down furniture, paper and paper products and wood panels from Asia and Europe.

Recommendations

- Concerted efforts to reduce forest degradation and enhance productivity in all types of forests for provision of forest products goods and services.
- The need for urgent strengthening many poorly organized players in both primary and secondary production to foster linkages and position them to engage the government and facilitating agencies in a unified voice.
- Production and consumption trends indicate growing demand and falling supplies hence the need for increased investment to enhance primary and secondary forest productivity, increased value addition and efficient infrastructure to serve both local and export markets.
- Operationalization policies and legislations to attract more actors and investment into the forest sector both at primary and secondary production levels.
- The forest sector need to be branded as a viable investment destination in order to attract more investments into saw milling and wood panel sectors to enhance competition and specialization for overall productivity and cost efficiency.
- The forest based enterprises need support to upgrade their technologies and improve their operational management through subsidized loans or concessionary credits.
- The policies and legislations in place provide opportunities for women, youth and minority group to fully participate in forestry activities but political power, traditional norm related to land and inadequate capital and skills hinder their empowerment.
- The furniture sector is dominated by artisanal operators and therefore need intervention measures through soft loans for investments in training on modern mass production, upgrading equipment and machinery for large-scale manufacturing that will increase overall output, productivity, sales, value addition and exports.
- Given that the vast market opportunities in the country and the wider Eastern Africa region Kenya can position itself to capture greater share relative to overseas furniture producers.
- The forest sector has potential to significantly contribute to the national economy and social development through job creation and income generation with removal hurdles that constrain the pace of establishment and development of the private forestry sector in the country.

Acknowledgement

Authors would like to acknowledge the African Forest Forum that supported the study through funding from Swedish International Development Agency (SIDA). Special thanks to Godwin Kowero, Executive Secretary and Doris Mutta the Project Officer for their useful contribution to the development of the paper and the various persons and organizations for providing data and other support accorded.

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Enhancing Partnerships and Resource Mobilization in Forestry Research and Development

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Abstract

Kenya Forestry Research Institute (KEFRI) gets 70% of its annual funding from Government of Kenya budget allocations and 30% from internal revenue and grants from development partners. For effective achievement in research and development, KEFRI establishes partnerships and cooperates with key strategic partners. This paper documents strategic partners of the Institute and their roles as well as the trends in accessing donor grants since1986. It places special emphasis on consultative collaboration between KEFRI and Kenya Forest Service (KFS) as sister institutions. It also outlines the key challenges and opportunities in partnerships and resource mobilization. It is reported that since inception in 1986, KEFRI has established 86 strategic partnerships and received funding and collaborative support from more than 20 development partners. The partners include; Government Ministries, State corporations, Universities, International organizations, donor agencies, private sector, International networks, Non-governmental organizations (NGO) and Community based organizations (CBOs). Despite existence of various local and international opportunities for funding forestry research, the low priority it receives is considered to be due to perceived missing linkage between research and sustainable development and the more specialized and complex nature of current research that requires new funding mechanisms to be identified. It is concluded that establishment of linkages with strategic partners is critical for creating synergies and complementarities in research and development. It is recommended that ways of mitigating the identified challenges and utilizing the identified opportunities should be explored for enhanced and sustainable resource mobilization and partnerships.

Keywords: Partnerships, resource mobilization, forestry research

Introduction

Kenya Forestry Research Institute (KEFRI) is mandated to conduct research in forestry and allied natural resources, disseminate research findings and establish partnerships and cooperate with other research organizations and institutions of higher learning in joint research and training. The Institute gets 70% of its annual funding from government of Kenya budget allocations. The remaining 30% comprises internally generated revenue and grant support by development partners. KEFRI having recognized the critical role of partners in accomplishing her mandate established a Partnership and Networks Programme in 1998 and a resource mobilization unit in 2012 which were later (in 2013) transformed into Partnerships and Resource Mobilization Unit. KEFRI through the Partnership and Resource Mobilization

Unit seeks to establish and strengthen synergies and complementarities with various partners to strengthen forestry research and development and to jointly mobilize the requisite resources to achieve this objective. KEFRI has currently a total of 86 strategic partners categorized as: Government Ministries, State Corporations, Universities, International organizations, County Governments, Non-governmental organizations (NGOs) Private Companies, and Community based organizations (CBOs). Some of the key development partners who have funded research and development work at KEFRI include: JICA, Finnish Government, Ford Foundation, GIZ, World Bank, African Development Bank, EU, DFID-UK, UNEP, USAID, IDRC and Pact-Kenya, among others.

KEFRI has pursued partnerships with the following aims:

1. Innovative research that combines various forms and sources of science (or knowledge) to increase the quality and likelihood of outcomes;
2. Legitimacy and credibility for important processes;
3. Access to a range of methodologies and tools;
4. Access to resource mobilization efforts place a premium on partnerships and most development partners will not fund projects and programmes without their involvement;
5. Access to different disciplines, necessary for forestry and related integrated natural resource management approach; and,
6. Greater understanding of the working methods and approaches of different partners, sectors, etc.

This paper documents the key partners (strategic and non-strategic), their roles and contributions to forestry research and development in Kenya. It further highlights the key contributions of KEFRI and KFS research and Management Liaison Committees and outlines the key challenges and opportunities in partnerships and resource mobilization for forestry research and development.

Role and Contribution of Key Partners (Strategic and Non-Strategic) in Forestry Research and Development in Kenya

Long-term/strategic partnerships

These are underpinned by common interest in the overall goals of poverty alleviation, food security, and environmental sustainability and other transformative processes and actions, and they bolster the contribution of forestry to these goals. The Partnership is formalized through a signed Memorandum of Understanding. A joint work-plan is then developed to implement the key areas of collaboration.

A strategic partnership is based on clear acknowledgement of the long term benefits and value-added in working together with a partner to achieve specific outcomes that benefit from complementary and supplementary strengths. See Table 1. Such partnerships entail observance of fundamental principles of equality, single-mindedness of purpose and clear distribution of roles and responsibilities bearing in mind the comparative advantages of the partners involved.

Project-based partnership
Defined by a joint project where the roles of each partner are clearly defined. A partnership that expires on completion of the project is formalized through a signed Memorandum or Letter of Agreement.

Table 1. Examples of strategic partnerships

Type of institution	Examples of organizations	Role
National research Organizations	NARIs e.g. KARI, KIRDI, KMFRI,KEMRI	• Collaboration in research and development activities and sharing of scientific information
Institutions of Higher learning /Universities	JKUAT, MOI University, Dedan Kimathi University of Technology, Kisii University , Kenyatta University, University of Nairobi, University of Eldoret, Pwani University)	• Collaboration in research and capacity building
Line Ministries	Ministry of Devolution and Planning; Ministry of Education; Ministry of Health, Ministry of Environment, Water and Natural Resource; Ministry of Industrialization and Enterprise Development, Ministry of Agriculture, Livestock and Fisheries; Ministry of Energy and Petroleum	• Provides funds for research and development to supplement funds from development partners • Transfer of relevant information to farmers • Support forest-based industries by transferring technologies for efficient processing of wood and non-wood forest products • Provides scientific information for sustainable management and utilization of medicinal plants • Provides guidance in science technologies and innovation policies • Contributes in formulation of environmental and NRM related policies.
State Corporations	KFS, KEWI, KWS, NEMA, ICIPE, ENNDA, ENDSA,	• Provides research extension services and linkages to farmers.

Type of institution	Examples of organizations	Role
	TARDA, CDA, KVDA, etc.	• Strengthens KEFRI's position through the Forest Products Research Centre in the value addition of a wide range of non-wood forest products, especially gums and resins, indigenous fruit trees, medicinal plants and bio-energy plants.
International Agricultural Research Centres (IARCs) and other Advanced Research Institutions (ARIs)	ICRAF, CIFOR, TSB, ICIPE, Bioversity, CAMCORE, ACTS, UNEP, UNDP, FAO, etc.	• Enhances collaboration regionally and internationally through various forest research networks • Collaboration in development of research proposals
Development Organizations &Conservation NGOs	Vi--Agroforestry, CARE -Kenya , World Vision, Farm Africa, IUCN, Action Aid,etc	• Supplements efforts of KFS in providing extension services
Regional & Sub-regional Organizations –	EAC-LVBC, ASARECA, IGAD, TAFORI, NAFORI, etc	• Collaboration in development of research proposals and project implementation
Farmer and Community-Based Organizations	KOMAZA, Baringo Aloe Bio Enterprise (BABE), Sandal wood farmers	• Enhances participatory forest management, capacity building and dissemination of research findings
Private Sector	Sigma feeds, Food & Cosmetic industries, Bamboo Trade Company Ltd, Kenya Gum Arabic and Resins Ltd (KGARL), etc.	• Utilizes efficient technologies in processing of forest products • Collaborates in research and development • Incubation of innovations

Trends on Donor Grants Since KEFRI inception

KEFRI has been supported by various development partners through funding of projects and programs for over 30 years. These include: Japan International Cooperation Agency (JICA), Belgium Technical Corporation, World bank, European Union, Ford Foundation, Food and Agriculture Organization of the United Nations (FAO), Canadian International Development Agency (CIDA), Swedish International Development Agency (SIDA), United States Aid for International Development (USAID), United Nations Development Program (UNDP), ASARECA, GTZ, UNIDO, African Academy for Sciences, WWF-UK, DFID, NALEP, Agricultural Research Fund, Care International, International Network for Bamboo and Ratan (INBAR), Clinton Foundation Adaptation Funds, Nordic Climate Facility, among others. The trends on donor grants since 1986 are as shown in Table 2 and Figure 1.

Table 2. Trends on donor grants since KEFRI's inception in 1986

Year	Donor grants KES (million)
1987/1988	1
1988/1989	1
1989/1990	3
1990/1991	-
1991/1992	5
1992/1993	23
1993/1994	20
1994/1995	22
1995/1996	10
1996/1997	6
1997/1998	4
1998/1999	9
1999/2000	25
2000/2001	19
2001/2002	36
2002/2003	36
2003/2004	26
2004/2005	24
2005/2006	44
2006/2007	46
2007/2008	46
2008/2009	49
2009/2010	45
2010/2011	51
2011/2012	39
2012/2013	87
2013/2014	102

Year	Donor grants KES (million)
2014/2015	82
2015/2016	364
2016/2017	270
TOTAL	**1,495**

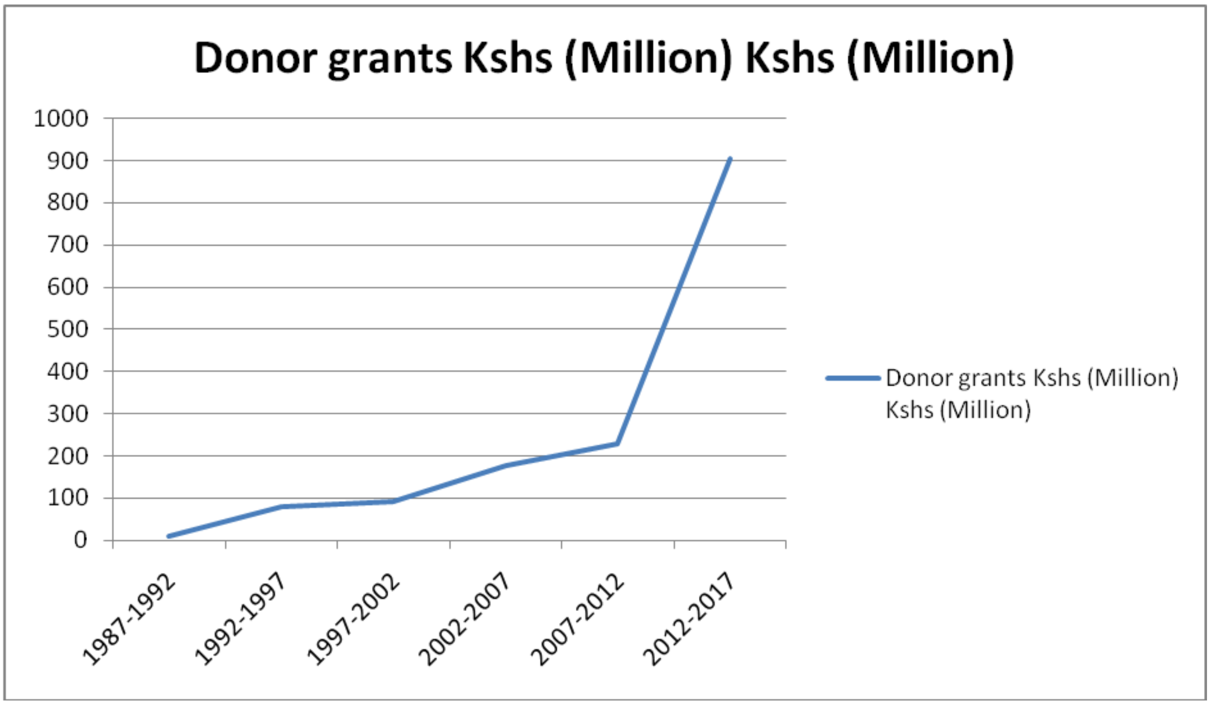

Figure 1. Trends of total donor grants received by KEFRI in 5-year intervals since 1987

Focus on Consultative Collaboration between KEFRI and KFS as Sister Institutions in Research and Development

The Kenya Forest Service (KFS) is the primary beneficiary and user of the information and technologies generated by KEFRI. In order to enhance the relationship between the two sister institutions, a memorandum of understanding on consultative collaboration (MOCC) has been in operation since 1994. It is reviewed once in every five years. The MOCC has put in place two (2) joint committees for the two institutions, one at the policy level, called the "Forestry Research and Management Policy Liaison Committee (PLC)" and the other at the middle technical level called the "Forest Research and Management Technical Liaison Committee (TLC)". The committees meet and consult from time to time to deliberate and give guidance on policy and technical matters on forestry research and management, respectively. Challenges that weaken effective linkages between the two parties are identified and addressed in the framework of this MOCC. The existence of other memoranda of understanding (MOUs) and agreements involving KFS and KEFRI with other partners is recognised. The MOCC has helped to enhance collaboration between the two institutions through:

a. Joint identification of management and research needs and priorities.
b. Involvement of KFS and other research information users at all stages of research planning, implementation, monitoring and evaluation.
c. Sourcing, allocation and use of shared resources.
d. Identification of training programmes and opportunities, expertise and information exchange.
e. Response to common national, regional and international issues pertaining to research, conservation, management, utilization and marketing of forest resources.
f. Development and review of technical orders, technical notes and guidelines.
g. Land for research and research facilities in forest reserves
h. Management and protection of seed sources and experimental plots.
i. Efficient tree seed storage and distribution.
j. Improvement of information dissemination and technology transfer.
k. Publication of a joint newsletter.
l. Joint training needs assessment and capacity building including sponsorship.

Challenges and Opportunities in Managing Partnerships and Resource Mobilization

For Kenya's future it is critical to strengthen research and development systems and institutions to enhance generation and application of quality knowledge and technology for long-term public support. In most African countries, conditions for research have been severely compromised as manifested by the generally poor remuneration, heavy research loads, inadequate research environment, low research incentives, time limitations to researcher, limited funding, inability to mentor young faculty, and in- adequate infrastructure. Below are some of the challenges that KEFRI as an institute alongside the partners have been experiencing in the course of undertaking forestry research:

Challenges

i. Research is given less priority in funding due to unaddressed missing linkage between research and sustainable development.
ii. Research field is becoming more specialized and complex and requires new funding mechanisms
iii. Low response to calls for proposals, concept notes and Letters of Interest
iv. Many concepts and proposals submitted not funded which is attributed to donor apathy to fund projects in the uncertain political situation in Kenya.
v. The high financial implications especially associated with consensus building meetings (on methods, tools, finances etc.)
vi. Limited resource mobilization skills and often not pursuing funding opportunities that are available locally, preferring international donors funding. Financial, project and organizational sustainability are lacking.
vii. Poor Networking. This causes duplication of efforts, leads to conflicting strategies at community level and failure to learn from experience and an inability to address local structural causes of poverty, deprivation and under-development. Negative competition for resources also undermines the reputation of the sector and the effectiveness of activities at community level. Many interventions at community level without any community mapping and implementation of projects without due regard to ongoing community initiatives.

viii. Development Approaches: There is a lack of sustainability and ownership of development interventions by communities. Some communities have been spoilt by dependency creating interventions and are not inclined to do things for themselves. It is difficult to keep programmes relevant to changing situations and the culture of handouts is hard to counter. There is no accepted code of ethics and conflicting approaches.

Opportunities

Partnerships and networking has enabled the institute to handle some of the above challenges in order to foster strong research support and implementations. Constant scanning of the research environment has enabled creation and identification of enabling opportunities that include:

i. **Existence of KEFRI Strategic Planning**: KEFRI has a strategic plan which can be used for resource mobilization and partnerships creation.
ii. **Existence of KEFRI resource mobilization strategy**: KEFRI has a strategy that stipulates objectives, approaches and methodologies towards resource mobilization to unify and shape focus for the resource mobilization activities. There exists **a policy** that stipulates motivations and remuneration structures for active and successful fundraisers which stirs fundraising actions.
iii. **Partnership guidelines**: Partnerships in KEFRI are guided by a document that spells the kind of linkages and modalities of reporting under each new partnership. This also unifies approach and strategies for souring and engaging new partners,
iv. **Local Resource Mobilization** provides potential for KEFRI to raise funds from local businesses through Public-Private Partnership (PPP), individuals and government (for example National Research Fund).
v. **Local Networking** provides opportunities for mutual learning, identifying appropriate development initiatives, generating learning resources, improving coordination and cooperation with local government, harmonizing approaches to development, and pursuing effective local advocacy. Form consortia to source funding from the donor community (larger projects to access larger donors).
vi. **Enabling Environment:** The new governmental dispensation has provided Kenyans with more political space to undertake their own development initiatives. People at all levels of society are more prepared to pursue their own development activities rather than wait for government and external actors to provide services, relief and welfare support. Improved infrastructure (roads, electricity, IT, communications, water, market access) provides more development opportunities to poor people and their communities. GoK is also enhancing the performance of its line Ministries, who are now all on performance contracts. GoK technical personnel are now willing to partner with NGOs who need not duplicate skills that are already locally available.
vii. **Government devolved funds and new funding mechanisms**: The constituency Development Fund (CDF), Constituency Aids Funds and other funds are available and can be accessed by developing proposals together with community based groups.

Conclusions and Recommendations

Establishment of linkages with strategic partners provides useful synergies and complementarities that are critical for forestry research and development. The Partnerships and Resource Mobilization unit should therefore catalyze capacity building and mentorship for the KEFRI staff as well as partner scientists in order to nurture a partnership culture. It is important that linkage between forestry research and sustainable development be made very clear to policy makers through exchange of relevant information and data so as to enhance reallocation of resources for research. Sustainable ways of mitigating the identified challenges should be explored. These include pursuance of joint research and development as well as joint fundraising between institutions. There is need to regularly enhance capacities of staff on role of partnerships in enhancing research quality as well as successful resource mobilization and emerging funding trends. Climate change is at the centre stage globally and there are many windows for forestry research and development. There is therefore a need to orient most of research work to offer mitigation and adaptation solutions which will in addition open up to the emerging and existing climate change related funding opportunities. The opportunities available for funding of research both locally and internationally should be documented and exploited in order to secure adequate funding for and development. Such opportunities include pursuance for joint development initiatives through Public-Private Partnership (PPP).

KEYNOTE

PRESENTATIONS

The Genesis of The Forestry Research Programme in Kenya, Establishment of KEFRI and its Subsequent Programme Performance

Keynote Paper

Dr J. A. Odera

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Introduction

Towards mid-1970s Kenya government had following the establishment of the National Council for Science and Technology (NCST), the government had launched thematic based research institutes. The government had further recognized the importance of investing in scientific research although overall investment in research still stood at less than 1% of the Gross Domestic Product (GDP), compared to developed countries that invested 2% to 3%. Against this premise, it was noted that application of science and technology had contributed heavily to economic and social change in industrial countries.

The objectives of this paper is to provide a background on the evolution of forest research programme in Kenya, highlighting considerations that led to instituting the national forestry research programme under the Kenya Forestry Research Institute (KEFRI), and subsequent KEFRI's performance. Achievements under different themes and gains realized through restructuring of the research programmes are noted, salient gaps identified, and areas where more concerted research and technological advancement are likely to open up opportunities for future improvements in land management are flagged. It is stressed that the need for addressing these topics remains an urgent and imperative task, because Kenya must increase wood and food production now, to meet the resources need of a growing population and the expanding levels of industrialization without major environmental (including ecosystems) degradation. Ongoing climate change and its impacts on the environment is an additional factor that is exacerbating the dynamics of land use, which must therefore be considered in the institute's research programmes.

It is widely recognized that the government recognizes the significant role of research in development and has mandated KEFRI to undertake applied forestry research with incidental elements of adaptive research. Available reports show that the institute undertakes intellectual investigations on the application of forestry in land use taking cognizance of the significance of the natural sciences, humanities, business studies and technology and their roles in terms of providing goods and services and contribution to national economic development, policy and institutional reforms.

This paper reviews areas where improved technologies developed by KEFRI's scientists provide and/or have potential to open up information and knowledge that will provide better approaches to the land owner, including forest managers, for informed decision-making. It is stressed that such information should take into account various scales of land use (e.g. plot, watershed, forest blocks, etc.). The roll outs should be packaged in a language easily understood by local people, must avoid technical jargons and be readily available to the public and private extension services, and held at the institute's resource bureau for use on demand. It is recommended that future research should as much as possible engage multidisciplinary and interdisciplinary participatory approaches that involve scientific, economic, and social components, along with local and regional knowledge systems. It is noted that KEFRI's current research rightly covers the entire forestry value chain and embraces a wide range of disciplines, including genetics and genomics, silviculture and stand management, forest health and pest management, ecology and biodiversity management, timber and biomass harvesting and haulage, site conditions that embrace soils, climate, socio-economics, and the environment.

An attempt is made to provide a common understanding of the role of forest science in development, resources use and management. Considerations that prompted discussions on the formation of a standalone forestry research institute are reviewed to provide contextual benchmarks for assessing KEFRI's performance.

Forest Science Defined

Forestry is widely viewed as a branch of applied science that promotes development of technologies for creating, managing, using wisely, conserving, and repairing forests and associated resources to meet desired goals, needs and values for human and environmental benefits. Modern forestry generally embraces a broad range of concerns, in what is generally referred to as multiple-use management, that includes the provision of timber, fuel wood, wildlife habitats, natural resources, recreation, landscape aesthetics, biodiversity management, watershed management, soil erosion, and preserving forests as "sinks" for sequestration of atmospheric carbon dioxide. In this regard, forest ecosystems stand as the most important component of the biosphere. To meet these tasks, forest practice must embrace biological, physical, social, political and managerial sciences.

Webster Oxford Dictionary (1984) defines research as: "A careful, systematic study in the field of knowledge that is undertaken to discover or establish facts or principles". Macmillan English Dictionary defines research as: "Undertaking a detailed study of something in order to discover facts = investigate".

A common question that researchers get from students and the general public is "what is your research good for?" To answer this question, it is best to establish the difference between ***basic* (*fundamental)*** and ***applied research***. **Basic research**, also called *pure research* or *fundamental research*, is scientific research aimed to determine what is going on, or improve scientific theories for improved understanding or prediction of natural or other phenomena. **Basic research** is curiosity driven. It is motivated by a desire to expand knowledge. This type of research tends not to be directly applicable under a specific practice in a direct way, but enhances understanding of the world around us. So, the real difference between the two types of research is what they will be used for.

By contrast**, applied research** is a type of research that is used to answer a specific question that has direct applications under a given practice, and uses scientific theories to develop information and or knowledge in developing technology or techniques geared to enhance quality/quantity in productivity or sustainability. It is therefore problem driven.
On the other hand, **adaptive research** is conducted to validate, modify, or calibrate a new technology to specific soil, climate, socioeconomic, or environmental characteristics of a given area.

Major Considerations that Stimulated Instituting the Forest Research Programme
The History and Development of Forestry in Kenya
The introduction of classical forestry in Kenya dates from the end of 19^{th} Century. Forestry management started in earnest with the introduction of new and fast growing species driven by the work of Hutchins, who had condemned indigenous species as part of a retrograde flora that had lost its resilience and were incapable of meeting the needs of a growing population. This paradigm was dropped briefly following disagreement with naturalists who had favoured use of indigenous species. But by 1926, experience confirmed that natural regeneration of most indigenous species was difficult and expensive, thereby paving the way for a resumption of the development of plantation of fast growing exotic species. The department introduced Australian and American species in the genera that included Eucalyptus, Pinus, Casuarina, Cupressaceae, and Grevillea, among others with seed from South Africa, Australia and America. Despite initial successful establishment and growth, some of the exotic monocultures turned out to be vulnerable to pests and diseases. Scientists and ecologists generally feared that following a short period on pest free “honey moon” monoculture plantations would fail altogether.

This, notwithstanding, the forestry programme remained focused on compensatory replacing of large areas with fast growing exotic species. This practice was particularly up-scaled immediately after World War 2. A few indigenous species such as *Juniperus procera, Prunus africana, Ocotea usambarensis, Brachylaena hutchinsii, Podocarpus falcatus, Vitex keniensis, Cordia abyssinica, Maesopsis eminii, Olea capensis*, among others, were also incorporated in the species trial programme. During this period, the bulk of research funds were allocated to species and provenance studies on exotic species. A few individual forest officers investigated regeneration potential of indigenous species and some stand treatment options. Consequently, forestry expansion and development was grounded in plantations, woodlots, and natural stands under ownership of state or county forest institutions, the Kenya Wildlife Services, the private sector/industry, and farmers.

This forest management practice continued into the post-independence era. Just before independence, the Forest Department prepared a guide to long-term industrial plantations investment and forest-based industries, particularly pulp and paper. The target was for

136,000 ha of sawn timber plantations and 24,000 ha of pulpwood plantations to be established by 1980. These plantations were made up of about 86% exotic softwoods (mainly pines and cypress), 10% Eucalyptus and others 5% indigenous hardwoods and softwoods. The exotic softwood plantations continued to dominate the bulk of Kenya's industrial wood raw material bases, while eucalyptus have supported transmission poles, fuel wood and to some extent, pulpwood and fibre-board needs. The government of the day had already recognized the central role of forests in our daily lives (Figure 1).

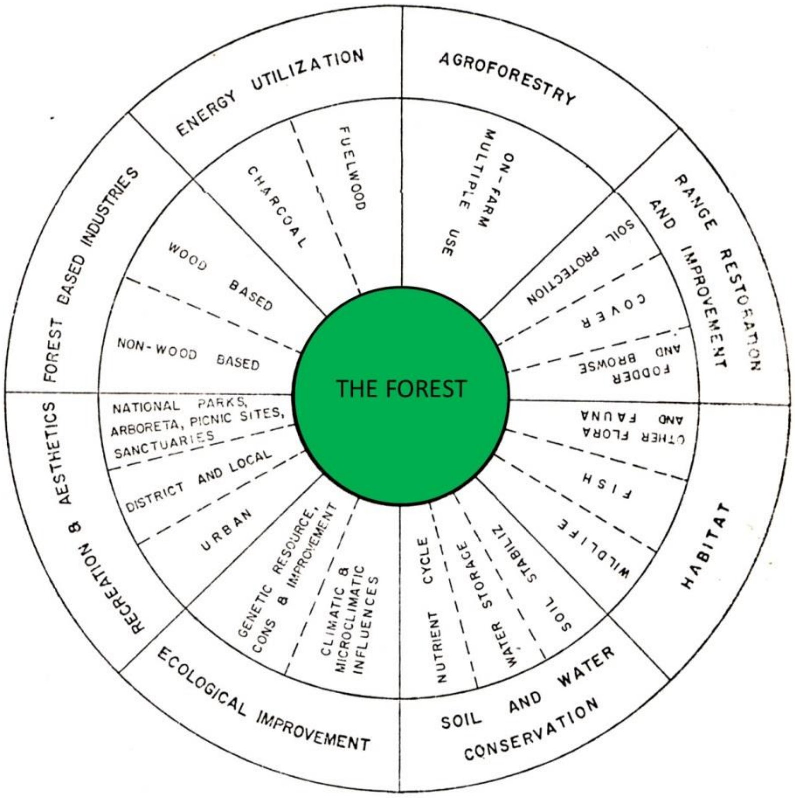

Fig. I THE CENTRAL ROLE OF FORESTS IN OUR LIVES

At independence, the forest administration which took over from the colonial system adopted the same policy and legislation. The revised forest policy as was restated in Sessional Paper No. 1 of 1968, re-echoed the dual role of Kenya’s forests for conservation and production. The relative ecological stability of the day did not provoke major regeneration activities by either the forest service (which seemed to focus exclusively on its function as the guardian of the forest heritage) or local communities who regarded the forest as an inexhaustible gift of nature. Consequently, the two parties did not see eye to eye and were on a collusion path, often seeking and hiding.

It was noted, at that time that plantations covered about 20% of the forest area and produced 90% of raw materials for the industries, with only 10% from the natural forests, of the national wood requirement. It was argued, in justifying this arrangement that plantations were supporting conservation by default through absorbing pressure from the natural forests by providing the bulk of wood demand, and thereby leaving the natural forests to support their traditional functions.

Emergence of The Forestry Research Programme

The Kenyan forestry research programme evolved from a simple background that was established by pioneer naturalists and foresters in 1920s. Early work had focused on reservation of land for the state. The first research officer was appointed in 1920s who launched work on silviculture and wood products, but precise forestry research programmes came after end of World War 2 in 1946. It was at this time that a silviculturist and an assistant silviculturist, an entomologist and pathologist were appointed. Kenya's research programme received a big boost in 1948 with the formation of the East African Agriculture and Forestry Research Organization (EAFRO). The nucleus of the Kenya forest research unit emerged with the establishment of the position of the conservator of forest in-charge of Research and Planning, followed by the establishment of an integral Research Conservancy in 1973 with responsibility for conducting research in silviculture, entomology, pathology and forest utilization. The EAFRO's forestry research programme had concentrated on quasi basic research on sub-regional interest such as forest genetics. The research programme had remained problem oriented often directed to solving problems on ad-hoc bases.

Concerns over the relatively low resourcing of the forestry research programme had reached public attention through lobbies by forest scientists, and proceedings of a national workshop that was held in Eldoret in 1983 and the observations made under the Kenya Forestry Master Plan produced in 1994.

A Summary of Recommendations of a National Workshop on Strengthening Forest Research in Kenya Held in 1983

The national workshop on strengthening forestry research in Kenya that was held in Eldoret in April 1983, had noted that although forestry's direct contribution to the GPD was relatively low (about 5%), its overall contribution is handsome, supporting virtually all sectors and the very core of the wellbeing of our people. Benefits go to social, economic, cultural and environmental systems. Beneficiaries of forest research outputs include the Kenya Forest Service, the National Environment Management Authority, the Department of Wildlife Services, the Ministry of Water Resources, the Department of Energy, The Centre for Biodiversity of the NMK, the wood and fibre based industries, the Fisheries Department, the Lands Department, the County Governments, the Regional Development Authorities, the Academia, the private sectors involved in tree cultivation and processing of wood and non-wood products, farmers and others. It was noted that the former Forestry Research Unit in the Forest Department was playing a second fiddle in the forest management programmes. The forest researchers had to shift to forest management positions to advance in their careers. At the same time, the Forest Research Department in the Agriculture research institute (KARI) was largely subservient to the bona fide agriculture research departments, an arrangement that ridiculed the Forestry Research Department to a state of perpetually low funding.

Under the two forestry research arrangements, forestry research scientists were compelled to work in non-conducive environments for scientific work and generally lacked visibility, political support and public good will. Financial support had remained inadequate and equipment was obsolete, facilities had heavily depreciated and governance systems lacked opportunities for rewarding outstanding achievers and performance recognition. In-service training opportunities and access to courses on skill updating and refinement were rare. The number of scientists was low and experts in many key areas such as forest genetics, tree breeding, tree physiology, biotechnology, non-wood products, socio-economics, among others, were lacking. Scientists lacked strategies for team work and bases for mobilizing multi-disciplinary specialists and experts for practical solution of complex problems. Table 1 summarises the recommendations of the Eldoret workshop

Table 1. A summary of the Eldoret workshop's recommendations

Problem	Recommendation
Inadequate mechanism for formulating national research policies and coordinating research for development programmes.	Mechanism be developed by the forest department for consultation among bodies interested and/or involved in forestry research to formulate research priorities for consideration at the national level by the NCST taking cognizance of needs &knowledge of all clients.
The lack of a comprehensive set of national forestry research priorities leaving room for addressing: (a) personal interests and extraneous politically driven projects, (b) conflicts between national, donor and user needs, (c) inadequate researchers' knowledge of realities in rural areas & poor contact with users of results/ target groups.	(A) All government & NGOs involved in forestry research to identify and respond to their clients' by providing technical knowledge with attention to national priorities. Researchable emergency/ crises calls (ie not defined in the national priorities) to be negotiated bilaterally with relevant research institution.
Lack of coordination between forestry research institutions, communication among researchers and holding regular project M&E.	• Forums be established to undertake periodic internal and external reviews & evaluation of forestry research as a permanent managerial function of research directors, • The ministry of finance and planning enhance support to forest research from the exchequer & development partners, • A Kenya Forestry Research Institute (KEFRI) be established to cater for all national forestry research programmes and to work closely with other government and NGOs involved in forestry research. • A National Forestry Research Advisory Committee be established to advise on forestry research programmes in all institutions. • Establish communication forums such as regular national forestry conferences, seminars, a research newsletter, a scientific journal and regular mass information outlets; • Periodic internal and external M&Es and evaluation of forestry research projects/programmes be adopted as a permanent managerial function of research directors.
Lack of a sustainable funding base for forestry research that assures the long term nature of forestry research.	Adequate provision be provided in the national recurrent budget to be supplemented by donor agencies.
Lack of channels for lobbying directly with donors and private sector to support priority research projects.	The ministry responsible for forestry research to provide a forum for regular meetings between the director, the development partners and the private sector. The research director to make active contacts

Problem	Recommendation
	with donor representatives and directors of relevant private bodies.
Lack of identity of forestry research at the national level.	A Kenya Forestry Research Institute be established to cater for all national forestry programmes and to collaborate with relevant government and NGOs.
Lack of coordination of forestry research programmes at the national level.	A national Forestry Research advisory Committee be established to advise and promote coordination of forestry n research programmes.
Lack of active communication and exchange between scientists within and between institutions.	KEFRI to organize a regular national forestry conference, scientific seminars and meetings, publish a research news letter, a national forestry journal and media coverage.
Lack of managerial skills in research administration, absence of motivation of scientists and technicians leading to inadequacy of a critical mass of scientists and technicians.	• Develop and implement a scheme of service for scientists that provides attractive career development and remuneration, gives credit for achievement in public. • Provide in-service training for scientists on new/supplementary areas of research and on managerial skills. • Increase awareness of career opportunities in research in schools and university.
Absence of: (a) participatory project planning and/or scientists user consultations, (b) Inadequate contact with target groups leading to poor identification of problems & user needs and concomitant deficiencies of results; (c) Delays in analysis, writing, publishing and adoption of emerging information and knowledge, (d) failure to assemble information and knowledge from research results in packages that are not readily applicable/usable by users, leading to low adoption/impact of research, (e) Clients do not know what to look/ask for, and who to ask, (f) weak scientists-extension services linkage, and (g) weak extension services due to low staffing levels and inadequate operational resources.	• Establish forums for joint scientists-user/target groups meetings to under comprehensive problem analysis and develop appropriate content of research (ensuring the necessary extent of multi-disciplinarity); • Ensure prompt & timely analysis of results and package the same in a language and form that is readily understandable and applicable by users who may not be familiar with the research jargon. . Engage an expert skilled in packaging new information in easily sellable modes; • Establish a central bureau in the research library to hold a compendium of past and ongoing research projects & emerging results by different land management regimes & eco-zones, etc.
Withholding release of research results including emerging technical information and knowledge (Dog in a manger attitude)	Minimize such delays through creating and maintaining horizontal exchange and vertical communication of progress in research implementation impacts.
Personal differences, rivalry & bigotry between scientists and institutions	The directors to create good/warm interpersonal relations within and between institutions

The workshop had therefore recommended that forestry research programme should be instituted in a standalone institute and apart from the Forest Service and the Kenya Agriculture Research Institute (KARI); in view of forestry's unique and increasingly critical contribution to development and long term future of the country. This arrangement was re-echoed in the Lagos Plan of Action for economic development in Africa: 1980 to 2000, (Published by International Institute for Labour Studies. Geneva). It was argued that this would further enable the forestry research programme to equitably address research needs and priorities of all its stakeholders and beneficiaries.

The Major Forestry Problems Facing Kenya Identified in The Forest Master Plan

The Kenya Forest Master Plan (FMP) that was launched in 1994, following deliberations by a team of experts on forestry, natural resources and allied land use disciplines from the government, international bodies, the civil society, with extra consultations across the board. The FMP had identified a number of challenges that were negating sustainable forest management in the country. Key challenges to SFM identified in the Master Plan include:

- Conservation and Sustainable Management of Indigenous Forests
- Developing the conversion of residual natural forests to other land uses,
- Lack of protocols for conserving forest ecosystems and their biodiversity,
- Failure to regulate forest use by local communities,
- Developing scientifically based sustainable management systems.

Specific Resolutions Made by KEFRI's Board of Management at its First Sitting in 1986

The board had resolved that:

- Kenya needs to create its own scientific capacity as prerequisite for economic, social and environmental development.
- The weak base of research scientists (12) should be raised incrementally by recruiting additional 10 scientists annually to reach a critical mass of 110.
- The institute should mount an aggressive training programme at the post graduate level, taking advantage of emerging cutting-edge scientific and technical skills.
- Develop and maintain a stable institution with a strong organizational base.
- Conceptualize a focused vision, mission and goal in relation to forest development needs and challenges.
- Improve infrastructure, equipment, and facilities at the headquarters, outstations and field outposts.
- Create a favourable environment for research, addressing physical social, cultural and intellectual atmospheres. and
- Develop an attractive scheme of service for scientific and technical staff that provide training, experience, and performance (innovation) with an attractive pension scheme that carry a good lump sum and an annuity.

The Kenya Forestry Research Institute On-The- Move

Kenya Forestry Research Institute (KEFRI) is a state corporation established in 1986, under the Science and Technology Act (Cap 250) of the Laws of Kenya. The Act has since been replaced by the Science, Technology and Innovation (STI) Act No. 28 of 2013. The director's report has confirmed that the first, second, third and fourth strategic plans had been implemented successfully, with reviews and evaluation at ends of each quinquennum, and lessons learned at the end of each phase ploughed in to the succeeding plan. The first and second plans had concentrated in addressing the challenges raised in the Eldoret workshop and the recommendations of the FMP. The fourth and fifth plans have further taken cognizance of the national second Medium Term Plan (MTP II) of the Vision 2030; the National Forestry strategic plan of the Ministry of Environment, Water and Natural Resources, the National Forest Plan and in consistence with the Constitution of Kenya 2010. It is noted that the current plan addresses five thematic R&D areas.

Salient Observations On KEFRI's Programme Implementation 1986 – 2016

Forestry is central in land use and supports virtually all sectors of the economy (Figure 1); it is therefore fitting that it approaches its work through multi-discilinarity, inter-disciplinarity and multi-sectoral approach that enables to bring on board expertise from relevant land use disciplines and basic scientific skills from problem analysis to knowledge packaging for application by resource managers.

KEFRI's research for development programmes serve six forest types (Western rain forest, Afro-montane forest, Coastal forest, Dryland forest, Plantations, and On-farm forests) from four 8 regional centres. The institute has conducted its work under a decentralized mode based in four ecoregions and five sub-centres, a strategy that enables the scientists to live and get to know the problems constraining forest development on the ground. This arrangement stand to allow for investigations to be conducted in selected eco-zones with the proviso that proven technologies would be extrapolated and/or piloted in related eco-zones, thereby saving on costs.

Available observations show that in developing its research programme that KEFRI has observed comments and guidelines from her constituencies and stakeholders starting from the Eldoret Workshop, through the Forest Master Plan and currently the National Forest Programme 2016 – 2030, taking cognizance of the Second Medium Term Plan (MTP II) of Vision 2030; National Forestry Programme 2016 – 2030. The need for ensuring that the institute's research remains problem-driven and geared towards serving the tenets of sustainable forest management remains an imperative task. It against this back-drop that we are going to take a brief walk through KEFRI's major Research themes:

Development in Forest Governance

KEFRI's contributions on the development of the National Forest Policy (2014) and the Forest Act(2005) provides a good example of how the national institute with a research mandate should back-stop the work of the parent forest body the KFS. Pioneering work on the development of participatory forest management (PFM) systems where KEFRI played a leading role, and assisted in the development of community organizational structures, that paved the ground for formation of CFAs has made significant contributions in grounding local community participation in forest governance. The granting of some rights to Forest Conservation Committees (FCC) and CFAs are laudable. The Forest Conservation and Management Act (2016) provides an enabling environment for good governance, access to public information, devolution, equitable sharing of benefits. It proposed that KEFRI should undertake follow-up tracer studies to assess performance of its intervention and to filter out areas deserving refinement and/or changes following information on reactions from the field.

Observations from the field seem to suggest that this work is not complete because the role and relevance of CFAs in counties with low forest cover remain unclear. While the CFAs are operating relatively smoothly in the Central Highlands and the Rift Valley, in Counties with low forest cover, Foresters or Forest Assistants have been posted to the sub-counties with rather limited or no resources for programme implementation. In the absence of a nearby forest estate, the CFAs cannot develop and/or operate income generating activities. The question that comes to mind is "can CFA operate in low forest cover Counties, in promoting the development of farm/social forestry programmes" ?

The role of communities through the CFAs in providing a watch dog role to the government in ensuring sustainable management of natural forests, forest plantations and farm forestry development is not coming out at all. Armed with the new Forest Policy (2014) and the Forest Act (2005), the PFM strategy was lauded as bullet proof tool for stemming corruption in forest management and development. Continued illegal activities in natural forests despite the ban on felling in 1985, and the recent ban on felling in plantations provide concrete evidence that all is not well. The managing of basic resource that supports many sectors, particularly local communities, through bans is more like "burning a house to kill a rat". People are suffering, institutions are accumulating losses and the entire economy is experiencing crises never recorded before. The KFS and KEFRI, with the latter taking a research role, are called upon to review and define the role of CFAs in such situations to enable the National Forest Programme realize its mission and goal across all counties.

Forest Policy and Legislation Revisited

Policies and legislations are dynamic and must be revisited from to time to bring them in tandem with changing values and perceptions. Despite the high stakes that were placed on the Kenya Forest Policy 2014, the Forest Act 2005 and supplementary rules, on-going public out cries over failure in management of natural forests and plantations signal failure in forest governance.

Pronouncement of dictums banning certain aspects of forest operations is not consistent with scientific management. The government had banned operations in natural forests in 1985 following reports of scandals over illegal of logging in natural forests. Despite this ban, scandals over illegal felling in natural forests, including cutting trees on water towers, stream edges and riparian areas against the provision of the Forest, Agriculture and Water Development Acts have been reported from time and again. Sending of foresters home in 2013; and the recent ban on felling in forest plantations due to growing cases of corruption, mismanagement, under revenues collection, fraudulent recording and book keeping spell regrettable challenges to the profession. Clearly hopes that the new policy and legislation would block corruption and mismanagement in forest development has diminished, provoking calls to researchers to go back to the drawing board to refine the forest management arena. The need to consider grounding elements of professional ethics, embodying integrity, transparency and accountability, in training in colleges and universities are worth considering, in addition to introducing tactics on inducting employees on how to abstain from corruption, establishing whistle blowing hot lines and conduction resources audit has been suggested. Can professional societies such as the Forest Society of Kenya help? What role can the Kenya Forest Working Group play?

The use of Criteria and Indicators (C&I) developed on recommendation made at the United Nations Conference on Environment and Development (UNCED) should be considered, with facilitation from researchers, for undertaking routine audits of management performance, and prospects of ensuring that set targets for assuring sustainable forest management, are running on schedule. The maintenance of good forests is the product of good forestry research, and researchers are therefore obliged to mount a comprehensive study on the instruments of forest operations, development and management to provide sustainable solutions. Bans on operation merely provide room for perpetuating forest destruction.

Forest Productivity Improvement

The development and improvement of productivity of trees and forests in all situations is the pillar and central activity towards overcoming the growing deficit in wood production; while enhancing conservation of the environment and biodiversity resources, landscape beauty and recreation. It was not possible to confirm if the institute accords commensurate resources (manpower and operating budget) to this programme to enable it play its lead role in the research for development arena. Silvicultural manipulation provides a useful tool for enhancing stand productivity. The institute’s research agenda seems silent on silvicultural research, without good reasons. Did the institute shut off silvicultural research from its agenda? This would be extremely unfortunate because silviculture in forestry is like agronomy in agriculture. I have yet to find an agricultural recommendation without reference to baseline agronomic practices. Clearly, one cannot resist asking about what happened to the many RE (silviculture experiments) some of which were running from the colonial times? It is strongly recommended that files on all REs, closed or running should be retrieved, data analysed to benefit the constituencies and to avoid new incoming foresters from having to reinvent the wheel.

Tree Improvement of Priority Plantation Species

Observations under tree improvement records importation and testing of superior genetic material, reports increased productivity of up to 40%. But it is clear from available documents to what extent the programme has benefited from earlier work on plus trees selection and concomitant testing of progenies and provenances. In this regard, it is proposed that the programme should examine data in closed EAFRO and Forestry Research Units files, analyse these and provide a more inclusive update provided on the state of national tree improvement efforts.

It is noted that the results have been rolled out through scientific publications, extension material, training course, open days, radio talks and TV presentations, shows, print media features and scientific conferences.

It is stressed further that KEFRI should strive to present its outputs in user focused packages for different categories of beneficiaries. This should be followed with a tracer study to provide feedbacks to enhance uptake and impact. Plantations with some fast growing species have been blamed for depleting the water table and soil nutrients. While the institute has provided information exonerating Eucalyptus species, there is still need to provide more hard data on tree water use by fast growing woody plants including bamboos. Some rural communities have observed that bamboo stands seem to be sterile with virtually no cover crops, while at the same time the ground remains hard and difficult to cultivate. Research should take this up provide hard data on attendant consequences of growing bamboos in farmlands.

The programme is also urged to use growth data from Permanent Sample Plot (PSP) systems embodying influences from the environment (altitude, rainfall, exposure, slope, and soils) , genetics, silvicultural systems, and other available geophysical information to provide informed models for informed decision making. Such models can be used in trend analyses and forecasting especially in extrapolation on cultivation of given species and/or practices in similar and related sites.

A toolkit for assessing soil quality and soil microbial community diversity and the levels of carbon sequestration, can also be developed from such cumulative data, and when available would greatly enhance understanding of the role of woody plants in enhancing fertility and environmental quality.

Production and Distribution of High Quality Tree Seed

The achievements under this programme are notable. Admittedly the responsibility for establishing tree seed orchards, seed stands, and training on selected topics should rest with the research institute. Achievements under this theme are commendable, but the state of the facilities developed under the GTZ technical cooperation seem to be a matter of concern. Funds should be allocated for routine repair and maintenance. It is noted further that the report is mute on what became of germplasm conservation in the form of seeds under joint arrangements with KARI. Long term germplasm conservation through storage of seeds of rare, endangered and improved (bred) materials should not be overlooked in the light of on-going changes in forest boundaries and accompanying excisions.

At the same time, it is felt that retaining the sale and distribution of seeds is merely creating an unnecessary burden, particularly because KEFRI lacks expertise in sale and distribution. This is excess baggage to a research institution, and should be off loaded, to release concerned staff to do research. Moreover, production of seedlings is largely privatized. In this regard, it is recommended that the sale of seeds should be privatized very much like agricultural crop seeds. Under this arrangement, the seed centre should process and package site and planting purpose matched seeds for specific eco-zones, with instructions for sawing seeds, raising seedlings and planting out guidelines. Such packages can be distributed through Agro-Vet shops, etc.

Rehabilitation of Degraded Natural Forests

I find investments under this theme to be rather humble vs its relative importance and potential contribution to sustainable forest management and use at local, county and national levels. The output on root causes of delayed recovery of degraded sites is welcomed. I see this theme as among the top layers where KEFRI's research tiers are the most likely to hit the forest management roads. The ban on resources exploitation in natural forests notwithstanding, the research programme should undertake applied research in these forests under secure state, community, county government land and in private land areas. Researchers should take advantage of on-going restrictions of anthropogenic influences during the ban on felling in natural forests and accumulate information on changes in forest dynamics under semi-pristine conditions. While respecting the force of the ban on felling, scientists should explore options for non-consumptive use of these forests. This would conveniently favour work on non-timber products, cultivation of mushrooms, sustainable harvesting of medicinal plants, among other activities.

Over time, this work should be extended to the littoral (mangrove forests), riparian forests, farmland residual forest patches, the sacred forests and in the arid and semi-arid lands (ASALs). Incidentally, the Kenya Forest Working Group (KFWG) has been working on forest recovery policy strategies project under UNDP funding. Can they provide some working information from this experience?

Forests in ASALs

The ASALs form a large chunk of Kenya's land area, but had remained ignored until recently. Forest reserves situated within the dry zone forest regions provide refuge for the surrounding pastoralists' communities who move into those areas to graze their animals during the dry seasons and periods of severe drought. Some communities undertake limited harvesting of wood and non-wood products, and making it urgent to consider supporting this need and use, thereby providing reliable safety nets that cushion the rural poor during periods of adversity. Forest research in ASALs call for applied and adaptive research by a multidisciplinary team of scientists from biological, physical, social, political and managerial backgrounds for its output to remain relevant to its wide constituency of land use practices. The research effort should address the entire forest value chain, thereby embracing genetics, genomics, silviculture, stand management, forest health and pest management, eco physiology, ecology and biodiversity management, wood and non-wood products and their values, biomass harvesting and haulage, product development and processing, and renewable energy.

Supplementary studies should further address forest influence on key ecosystems services including soil and water resources, sedimentation and processes of climate change, including increases in temperature and increasing frequency of extreme weather and their impact on the environment. These variables can be measured using criteria and indicators with modern rapid cost effective low cost resources quality procedures.

It is also stressed that some work should address prospects for enrichment planting and aerial seeding as strategies for fast tracking the recovery processes. In looking at the harvesting, processing and consumption end of the forest value chain, the research effort should explore prospects of implementing sound exploitation based on sustained yield management with strict annual allowable cuts from each forest area to provide the country with Kenya's valuable red woods from natural forests on a sustainable basis. Research should further explore opportunities for introducing income generating programmes from available resources including adoption of climate smart landscape multifunctional livelihood benefits. These would enable local communities internalize long-term perspective through derivation of benefits and stewardship.

Conservation of Rare, Endangered and Threatened Species

It has been reported that about 300 species of plants are endemic to Kenya, some of which have restricted ranges of distribution. The Kenya Forest department, the predecessor of the KFS had established Nature Reserves in strategic and representative sites in the natural forests, where all forms of germ plasm harvesting was prohibited. The forestry research programme maintained these Nature Reserves, and undertook regular monitoring to determine the breeding potential and sustainability. On one occasion the research programme under took actual planting of a species of Tecleopsis, when its numbers had proved to be declining in the natural forest in Muguga. Nature reserves provide the last fortress in the defence of a threatened/rare/endangered endemic species from possible extinction. This activity should be revived to enable the country save affected species.

Technologies for Sandal Wood Propagation

The news about benefits of growing sandal wood had exited many Kenyans including our leaders. KEFRI's response to this demand was commendable, being consistent with national aspirations and people's expectations from its national research institution. Guidelines on propagation of plantlets and establishment of plots are properly prepared and easily understood by local people. With growing paucity of cash crops in land use systems, cultivation of this species by a critical mass of famers and institution is a must. A strategy that would make this happen lies on:

- Assessing presence or absence of varietal differences in potency of base chemicals and hence popularizing the superior provenances.
- Promoting a critical mass of farmers to grow it in agro-ecological zones that are suitable for its cultivation.
- Incorporating the species in forest management and development in appropriate eco-zones, through working with relevant outreach (extension arms) with clear guidelines

on handling its cultivation across the entire production chain, including technologies on sustainable reduced impact harvesting and product marketing.

- Packaging the developed technologies and passing these for adoption at farm gates for interested farmers and land owners to maximize adoption for enhanced income generation to stabilize local livelihood strategies and economy.
- Popularizing the cultivation of this species using developed technological packages through establishing demonstration plots, releasing bulletins held at the resource centre, the media and other outlets.
- Pilot/demonstration plots of Sandal wood species should be established in all areas with suitable sandal wood growing conditions to enable interested farmers grow and benefit from this lucrative crop.

Diversification of On-Farm Tree Species

On-farm tree planting is gradually becoming a success story in Kenya. I recently flew over parts of western Kenya and Nyanza and was impressed by increased tree/forest covering some Counties. An increasing number of farms are incorporating trees under live fences, woodlots, fallows, etc. What farmers continue to lack are:

(a) Access to reliable sources of site – certified seeds that are consistent with farmers planting goals including poles, food resources, medicines, etc.

(b) Prospects of benefitting from a wider base of germplasm outside the range of traditional species from the wet highlands;

(c) Lacks of opportunities for inject a strategic thrust to increase the productivity, commercialization and competitiveness of farm forest products.

In this regard, planting of emerging Cinderella species such as *Melia volkensii* should be extended to other sub-humid areas in the country. It has been observed that some species such *Terminalia ivorensis*, *Antiaris toxicaria* and teak, are performing well in moist to sub-humid part of central Uganda. These and others may be good candidates for consideration in similar/related growing conditions in western Kenya and at the coast. The significance that KEFRI had placed of *Melia volkensii* is beginning to pay off dividends. The work on identification of superior trees should be extended into a breeding/tree improvement programme to cover all eco-zones where this elegant species can grow.

Farm forestry in a key area where KEFRI's tires are likely to hit the road and should not be rolled out as a hobby. Researchers are urged to develop prototype farm forest management plans along a value chain focusing on open niches on-farm and dovetailed on to the growing momentum of community based forestry being touted under FCCs and CFAs, which has hitherto eluded areas with low forest cover at the coast, southern Kenya, Nyanza and western Kenya. Planting should favour multipurpose fast growing (genetically improved) tree species for poles, woodfuel, wood carvings, and utility non-wood products, and to meet social, economic, environmental and climate change strategies. Forests in agroforestry and social landscapes relics of sacred grooves can be included under this initiative. This intervention should be strengthened by developing a sustainable land use policy.

Given the broad face of Kenya, such success stories with local institutions should be extended to all agro-climatic zones, counties and sub-counties, focusing on relevant tree planting niches; with management imperatives addressing entire value chains, including product processing and marketing.

Farm Productivity through Agroforestry Systems

Work on agroforestry research has been on the ground for some time, following ICRAF's location in Kenya in the early 1970s. It is not clear from availed material if any of KEFRI's experiments have been concluded and written up. Are we seeing a perpetuation of studies that should have been concluded, results written up, data published and experiences with clear templates on specific technological packages developed? It is also conspicuous that the results of pioneer classical agroforestry work on Alley cropping, Hedge Row intercropping and related work on soil fertility replenishment may well have ended in scientific journals. Such results should be repackaged and rolled out to farmers in ready to use kits. I wish to single one technology on application of *Tithonia* green mulch plus rock phosphate that was developed in Maseno, and is currently used by farmers in western Kenya. Some farmers are taking this technology a notch higher by preparing *Tithonia* biomass as liquid manure. Can KEFRI take this up and assist our farmers in valorizing this product through provision of back-up technical information. A similar product is being marketed under a brand name *D I Grow* from Malaysia, but clearly inferior to *Tithonia* infusion.

It is against this back-drop that I wish to urge our researchers to explore prospects of valorizing some of the products such as drying leafy biomass into hay or pellets for chicken feed stocks, for storage and use during forage scarcity seasons. Overall continued relevance of these studies should be backed up with results of a tracer study to assess available information and knowledge packages developed from past work vs the technologies that have been adopted by eco-zones and benefits practicing farmers are deriving from practicing these technologies.

Management and Monitoring of Tree Pests and Diseases

KEFRI has recorded notable milestones under this theme. Fears of severe catastrophes of pests and diseases in plantations of exotic species following an initial pest free "honey moon" has been forestalled through maintaining vigilance and applying effective remedial measures. This positive mark notwithstanding, it seems prudent for the theme to consider IPM strategies that integrate selection and development of resistant species and varieties, and development of silvicultural systems, alongside practicing biological control methods. It is not clear, in this regard, if the breeding of Dothistroma resistant varieties under the Pan African Paper Mill support has been concluded, outcomes, and results of progeny tests.

Management and Control of Invasive Prosopis Species

At the time of initial introduction of woody plants in dry lands, consideration was given to what could meet the government's objective of increasing tree cover with drought tolerant multipurpose species, of which species of Prosopis were good candidates. Successful introduction of these species in Kenya's drylands, was suddenly choked with reports of the nutty experience with "*Mathenge*" in Baringo. KEFRI's prompt response to this problem, and development of how a productive system of its sustainable management are clear demonstrations of a national research programme should tackle set of national research priorities, while leaving flexibility to address emergency uprisings. The results continue to add additional colourful feathers to the institute's hat. Many more such success stories are needed to enable the institute gain recognition in the planning and finance desks and hence gain political good will and public support. This would provide a bargaining chip in negotiating for additional funds. Internally, the institute can enhance such drives through developing a system for rewarding researchers for quality work, speedy response to local concerns and for innovation.

Forest Products Development

The value of woody plants will continue to be seen in the mirror of the use of their products – goods and services – in human life and the environment. KEFRI's work on promoting technologies for efficient product development and processing stands at the cutting edge of its research programmes. The importance of strengthening KEFRI's strategic thrust for increasing the productivity, and commercialization of competitive forest's goods and services, remains an urgent and imperative task. In deed this is a central pillar for creating jobs, supporting the green economy and mitigating poverty and improving food security. Accumulation of hard data on productivity of wood and non-wood products and quantification of ecosystems contributions to macroeconomics performance in development, hold the key to enhancing forestry's contribution in the government's books of accounts.

Efficient on-Farm Timber Processing

Investment in this work is timely, because without tangible benefits, farmers would be reluctant to continue investing on tree planting. Currently farmers are experiencing considerable losses through using conventional chainsaws that conservatively, may run up to 20%. This apart, chain sawing has a clear advantage through eliminating costs of haulage through on-farm conversion.

The development of an improved mobile framed chainsaw system provides an important breakthrough, with clear advantages in its output. Further research should consider developing additional options for improving processing efficiency through reductions in the chain thickness, and to provide hard data on actual farmer benefits from this technology.

Development of on-farm processing should also consider providing the farmer with an enabling policy environment. Currently, chain sawing is being abused by local administration, who demand as much as KES 1,000/= per chain saw per day even where a farmer is sawing logs for own domestic use. This is killing tree planting effort and may negate the government's drive to realize 10% forest cover by 2030.

Adoption and Utilization Of Bamboos In Kenya

Successful introduction and cultivation of lowland species of bamboos is a plus and adaptive research on product development, particularly back yard based processing to provide different utility products should be maintained on the front burner. It is also prudent to assess bamboo's influence on soil and water management. This is because bamboo stands seem to be sterile, the soils remain hard and difficult to cultivate, while water tend to ooze profusely from roots where trenches are cut on the ground around bamboo stands. KEFRI should be at the fore front in developing a low cost household based structure specialized in product development, processing and value addition and sale of bamboo products. Such a project would suit women and the youth.

Wood Carvings

This is a sleeping Giant whose exploitation falls well below its potential due to lack of government attention. Consequently, the quality of carvings remain low and lack in-depth processing and value addition. It currently caters for casual tourist who are content with showing an item to vindicate their travel to Africa. The rich shop keepers buy these and process them further in their back-yards and sell finished products in the up-markets. The promotion of neem logs for carving production under certification process apart, the government should consider injecting some training investment through teaming with tourist board, and aim at production of quality products for sale at a premium to enhance revenue generation and conservation of raw materials.

Biomass Energy Production Technology

This study is at the core of forest product development and processing, a platform where values and benefits of forestry are presented and discussed. The product further touches on the economy that supports an increasing number of the emerging rural middle class, and the working population in towns, urban and market centres. It is also noteworthy that the study has been running for quite some time and many of its components must have been concluded, unless these were open ended and not time bound.

It is recommended that:

a) All concluded components of this work should be analysed, outputs packaged in modes that are readily adopted and used by stakeholders and beneficiaries for the good of the economy and human welfare
b) What does this project say about different designs of wood burners including gasifiers that are sold in the market
c) A few years ago, I read repots of small timer entrepreneurs who was converting thinnings and undesirable woody species removed during mechanical weeding in natural stands and/or plantations, into charcoal using “Uganda mark 2” metal kilns. The latter were transported at the back of a pick-up and shifted from one site to another to minimize haulage costs. Do we space for such an enterprise in the rural Kenya

It is felt that KEFRI should take a stand on transport and sale of charcoal, particularly in the light of the ban on charcoal production in some counties. Charcoal production, and transportation seems to remain illegal, while its sale in yards and consumption in houses is legitimate: a stalemate that has persisted from colonial times. This calls for an urgent development of a policy statement, otherwise the country will revert to piracy and black marketeering. Production of charcoal must remain accessible to all channels leading from producers to consumers must remain open to all ranks across all ecological zones. Under good practice, guided by approved and logical policy statement, products harvested within periods of silvicultural management must be legitimate, and be pursued to logical ends of the value chain. Denying growers access to benefits of their sweat is a clear act of sabotage that will only kill forest development and management at best and create room for corruption during production and distribution. KEFRI Help!!!

Development and Extraction of Non-Wood Forest Products:

Sustainable Utilization of:

a) Gums and Resins
b) Development of indigenous fruit products
c) Medicinal plants
d) Identification of alternative species for wood carving,
e) Promoting adoption and utilization of Bamboos in Kenya; all stand to enhance the sources of sustainable flow of utility products from forests. It is often stressed that farmers will not hesitate to uproot any plant that does not provide tangible benefits to them and their families. Results of concerted research in these areas hold great potentials for benefiting many Kenyans through creation of jobs, income generation, improving health, promoting political support and public good will, and thereby help locals develop acceptance of forestry in land use.

The work on gums and resins has placed Kenya in the world map in line with such big gum producers such as Sudan and should be expanded to enhance benefits to dryland communities. Such studies should inter alia investigate lack of gum production among *Acacia senegalensis* in Southern drylands including Kajiado.

The management of medicinal plants calls for a more concerted attention, to be undergirded by an appropriate policy statement and enforcement instruments. The industry support over KES 1m annually, and growing, putting herbs at risk of being wiped out unless protected. When sustainably managed these herbs, some of remain undescribed but have potential of treating many problem diseases, to the benefit on mankind.

Activities reported under this effort should be extended to all forests.

Valuation of Forest Resources

Forestry has suffered from lack of recognition due to lack of ways and means of quantifying its many intrinsic environmental functions and services; and trading of its products in non-formal markets. The values of these products have largely been expressed subjectively in the absence of methodologies for measuring forests' indirect contribution to ecosystem services into shillings and cents. Planners and government coffers officials have accorded little recognition of descriptive values of forestry under tight competition between sectors/ministries for funds. Results of recent KEFRI's studies has opened gates into a virgin area of studies on non-traded values of forest resources. A paper by Langat and Cheboiwo (2010) provides a path setting study on this regard, and should be extended to all water towers embracing those of prominent, medium and little status. The catchments supporting little springs in the country sides are just as important in this regard.

Such studies should also incorporate counties and urban areas that trade on water resources, i.e. these counties draw water from dams, rivers and lakes, treat and sell it to their residents on a user pay principle. Dealing with institutions may well be easier than individual land owners. Experience from elsewhere show that cities, such as the New York City, pay handsome amounts of money to landowners who are practicing conservation in catchment areas from where they draw water.

Infrastructure Human Resources Development and Resources Mobilization

The Kenya Forestry Research Institute has made commendable strides on infrastructural development and provision of facilities at its head office and in the regional centers. The stretch of the decentralization process is also in keeping with the country's constitution and strategy for promoting balanced national development. This brings forestry research to the people equitably and stands to build competence for strengthening each County's capacity to tap its comparative bio-ecological advantage in development.

Another plus comes from the improved staff base of scientific staff. With its attractive scheme of service, and pension scheme, KEFRI is keyed to grow into an institute of excellence in scientific research for development that is capable of attracting and retaining achievers. The ratio of technical staff to the scientists stands at about 2:1. Some institutions seem to favour 3 or 4 technicians to 1 scientist. But at its present setting the institute is also likely to lose opportunities of benefitting from its cream of scientists as they take senior administrative position. Programme leaders in positions of senior deputies and above become too busy with administrative, M&E responsibilities, besides attending meetings and are unlikely to have time for hands-on research. This handicap that is currently associated with career development should be reviewed to forestall losses in scientific capacity which the institute has built over some time. The institute's training record is good as it covers the undergraduate, and post graduate levels. It would seem though that training at the undergraduate level has eroded its base of technical staff. In this regard, this strategy may need to be reviewed. Under this setting technicians should be left to advance along their own career lines.

Technical Support Services

The Institute's decision to invest in the development of specialized laboratories providing services on soil chemistry, pathology, tissue culture, molecular genetics, entomology, tree seed, wood science, and phyto-chemistry is laudable. Out sourcing services for basic information in these fields, can be expensive and is often subject to delays as different institutions may be queuing up for services at the same time. This is likely to slow down progress in implementing the main project under investigation. It would be prudent for the institute to take up services from other institutions and/or individuals on payment of a fee, to boost up revenue, particularly for equipment maintenance and servicing.

It is noted further with satisfaction that KEFRI has in-house competence for handling different statistical packages, research protocols, GIS, and remote sensing in supporting relevant studies, and to provide world class results.

Knowledge Management and Knowledge Packaging

This is one of the kingpin units of the institute, and the clearing house for its results. It is also the institute's organ that interfaces with the stakeholders and beneficiaries of KEFRI's research products. Scientific research is conducted to generate information that is subsequently used produce knowledge. The bulk of KEFRI's research is largely of applied nature, demand driven and targeting problems identified during joint planning by the stakeholders/beneficiaries of results and scientists from KEFRI and allied land use agencies. A small volume of research is undertaken in response to emergency problems on calls by the stakeholders. Some queasy basic research is undertaken in collaboration with scientists from other institutions such the universities. A third category of research is of adaptive nature and is undertaken to validate and/or calibrate new technologies to fresh environments. Relevant examples include work on new genetic material, and calibration or adapting processing of technologies developed elsewhere.

It is noted that KEFRI's research results are: (a) released in scientific journals and technical papers and posters are presented in seminars and conferences, for consumption by peers and technical leaders and administrators; (b) grey literature; and (c) flyers and brochures. Specific information generated from these outputs is package in leaflets, bulletins, policy briefs for decision makers. Show cases on the state-of-the-art are displayed in demonstrations plots on station and on-farms, and in the show grounds.

After browsing through some of the packages listed above I wish to suggest that results should be directed to specific users, particularly those going to land use extension services, farmers and forest managers. Such bodies of information should be packaged in formats that are easily understood by recipients, and where it is possible in languages they comprehend. A few examples where this has been done were noted.

In addition to this, KEFRI should strive to: (i) engage recipients in packaging the results, in addition to involving them in problem analysis during strategic planning, (ii) undertake tracer studies to assess performance of the new technologies in the field, and where it is necessary recognize impacts.

After recognizing this unit as the clearing out for techno-scientific information and knowledge, I was unable to see guidelines on how the institute handles innovation on areas that touch on intellectual property rights. In the event that this is not in place, the institute should develop guidelines on benefit sharing, to safe guard possible conflicts between researchers and the institute in the event an individual or teams of scientists discover or develop a marketable technology.

KEFRI's current strategic plan has given commitment to undertake research by multidisciplinary and where it is necessary through interdisciplinary alliances. Apart from the lists of publications, this lists that lists joint authorship; information on the structure, does not provide space for team work. It is hoped that each project has a clear layout of roles of all players, including the levels of inputs by each player. It is observed that with the changing roles of forestry in development, mono-disciplinary approaches are unlikely to provide bankable technologies.

Creating an Enabling Environment for Research

Looking back with a hind sight, in retrospect, it is notable that KEFRI has addressed concerns raised earlier over weak resourcing of the forest research programme. The institute has developed and is implementing an attractive scheme of service, and a pension scheme. It has provided an in house clinic at the headquarters. Regional centres and sub-centres have brought scientists close to the people and field ground, thereby enabling them to live and know the challenges at first hand. Modern offices, laboratories and equipment at the headquarters and centres provide useful back up for critical investigations and research. This is further enabling the institute to attract and retain competent scientists, technical and support staff.

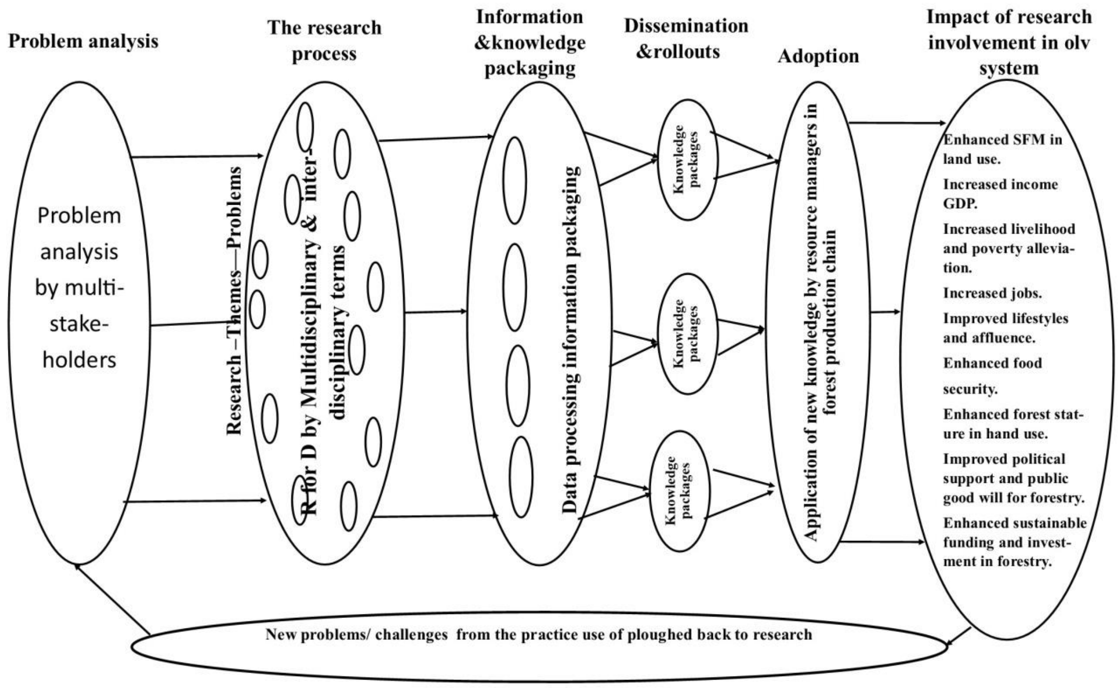

Figure 2. Research Activity Flow from Problem Analysis to Product Output

A Summary of Recommendations

To be able to improve and retain gains noted in this paper the institute should consider addressing the following:

1. Set performance targets for each staff, aligning each with objectives of the job, programme, and the institutes mission, vision and goal; and create a structure for rewarding achievers/innovators, and for censuring laggards, joy riders and those given to deviant behaviour and conduct. Achievers should receive cash bonuses and awards, promotion and public recognition; while those sleeping on the job should be shown the door.
2. Restructure the research from the predominant mono-discipline approach to multidisciplinary/interdisciplinary arrangement (Figure 2). Under this approach biological scientists must be refrained from doubling up as social, cultural scientists

and co-opting the specialists instead. This would save money and time, besides providing quality pedigree results. Assembling the team of specialists and drawing their TOR should be supervised by the Deputy Director in-charge of Research to avoid conflicts of seniority.

3. Develop provisions for managing intellectual property rights, and a structure for equitable basis for benefit sharing.
4. Conduct tracer studies on technology adoption to oversight performance impact on livelihood, forest development, and environmental services.
5. Conduct regular M&E on progress implementation a comprehensive scientific audit on overall performance.
6. The KFS and KEFRI should develop a protocol on mutual support that would enable the two institutions to work together reciprocally and supportively to enhance forestry's performance in national development. This would forestall feelings of mistrust and rivalry.
7. All studies should follow well designed methodologies developed with help of a biometrician, use of modern tools and equipments; and emerging data analyzed scientifically to provide versatile models capable of enabling trend analyses, and forecasting for ease of interpretation and extrapolation to similar and/or related situations.
8. All success stories should where it is possible be replicated in demonstration plots in accessible sites.
9. All old research files should be retrieved and analysed.
10. All Kenyan research records should be collected and kept safe archival custodies.

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Webster Oxford Dictionary (1984)

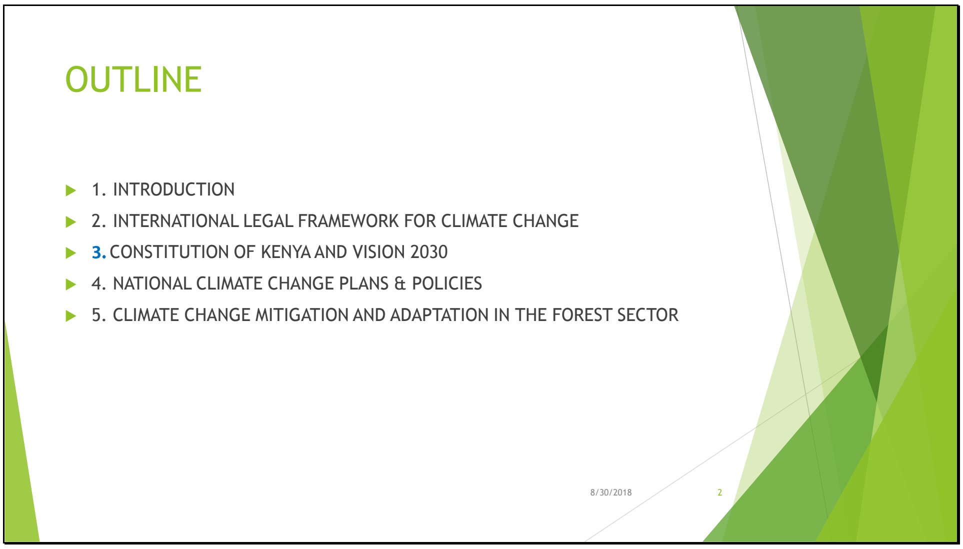
Challenges of Climate Change in Kenya with Reference to Forestry and Allied Natural Resources

Keynote Presentation 2

Dr Pacifica F Achieng Ogola

Director Climate Change Programme Coordination
Ministry of Environment and Forestry

Slide 1

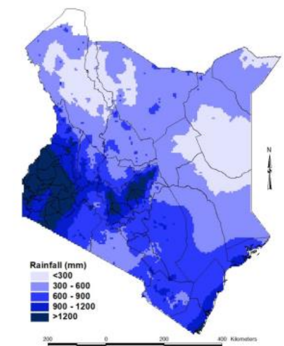


Slide 2

1. Introduction

- 80 per cent of Kenya receives less than 700 mm of rain per year and is classified as arid or
- The high and medium rainfall areas of the country are located in the western and central highlands, areas near Lake Victoria and parts of the Rift Valley.
- Rainfall patterns have also changed. The long rainy season has become shorter and dryer and the short rainy season has become longer and wetter
- Impacts: floods, malaria, water borne diseases

Figure 1.2: Map of Kenya showing annual rainfall across the 47 Counties

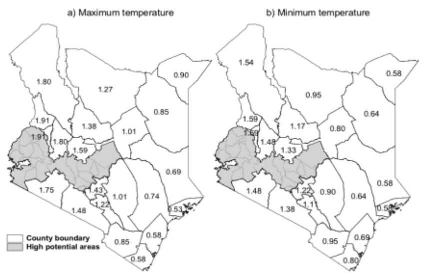


ource: Government of Kenya, 2016

Slide 3

Introduction

Figure 1.3: Temperatures changes in the Kenya 21 arid and semi-arid Counties between 1960 and 2013



Source: Said, M.Y., et al. (2018) Climate projections for Arid and Semi-arid lands of Kenya based on RCP 2.6, RCP 4.5 and RCP 8.5. PRISE Research Brief.

Kenya has experienced a general warming trend, reported as being about 1°C, or 0.21°C per decade Since 1960.

Temperature increase observed across all seasons, particularly from March to May.

Impacts: droughts, reduced access to water resources, loss of livelihood

Forests also play a vital role in adaptation to climate change

Slide 4

2. INTERNATIONAL LEGAL FRAMEWORK FOR CLIMATE CHANGE

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3. International Climate Change Regime

UNFCCC 1992 drawn up at 1992 Rio Earth Summit

- Came into force in 1994
- Framework Convention
- Ratified by 197 countries
- Objective is to stabilise GHG emissions

Kyoto Protocol (KP) 1997

- Came into force in 2005, 192 parties
- Developed to meet the ultimate objective of the UNFCCC which is to "stabilize GHG concentrations in the atmosphere at a level that would prevent anthropogenic interference with the climate system"…. through quantified emission targets within a specified time frame.

- KP First commitment period (KP1): 2008-2012 (prescribed emission reduction targets for developed countries)
- KP Second commitment period(KP2: 2013-2020
- 2015 Paris Agreement comes into effect in 2016.


The Japan Times
Conference adopts Kyoto Protocol

Slide 6

Paris Agreement in Context

- 12 December 2015, 197 parties to the Convention agreed the first global international climate change agreement;
- 175 out of 197 parties have ratified;
- On 5 October 2016, the threshold for entry into force of the Paris Agreement was achieved;
- Entered into force on **4th of November 2016** a month after meeting the threshold;
- Considered an international treaty under the Vienna Convention;
- Employs a “hybrid legal structure,” with both legally binding and nonbinding components;
- Employs a top-down, rules-based system and a bottom-up system of pledge and review.

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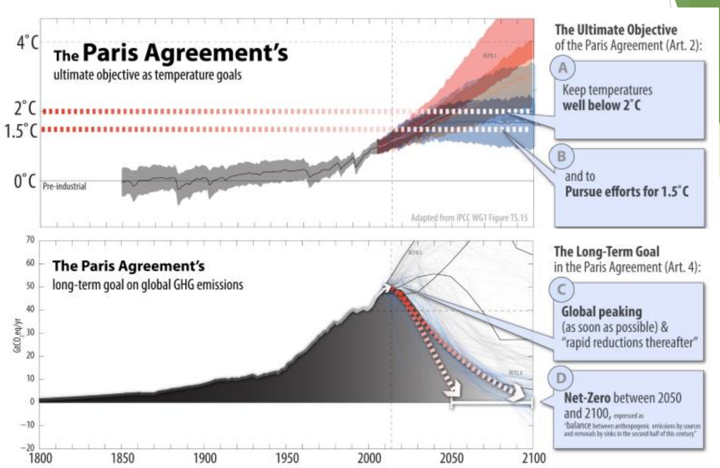
Slide 7

Paris Agreement – long term global goal



Source: M. Meinshausen, Australian-German Climate & Energy College, The University of Melbourne, climatecollege.unimelb.edu.au

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Forests under UNFCCC/ SDGs

- The main cause of climate change is the **anthropogenic** increase in greenhouse gas concentrations in the earth's atmosphere.
- Intergovernmental Panel on Climate Change estimates of the global mitigation potential from forests are substantial - chapter on Forests
- Adoption of the Kyoto Protocol 1997 encouraged individual countries to increase the rates of carbon uptake and storage in forest biomass.
- Carbon sinks are also supported through the so-called voluntary carbon offset market outside the Kyoto Protocol, and World Bank initiatives like the Biocarbon Fund.
- Reduced Emissions from Deforestation in Developing countries (REDD)+ - article 5 of the Paris Agreement

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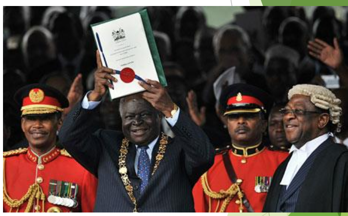
3. CONSTITUTION OF KENYA AND VISION 2030

Slide 10

CONSTITUTION OF KENYA 2010

- Recognizes the environment as a heritage for all Kenyans that must be sustained for future generations Sustainable exploitation of natural resources;
- Requires that all existing policies, laws and other instruments be aligned to it.
- Defines the vision and principles necessary to steer the country's environmental and climate change agenda;
- Specifies the obligations of different stakeholders in respect to the environment.



H.E. former President on promulgation of the Constitution of Kenya 2010.

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CONSTITUTION OF KENYA 2010

- Constitution of Kenya 2010- mentioned in the Climate Change Act, 2016
  - Article 10: National values and principles of governance
  - Article 35: Rights to access information
  - Article 42: Every person has a right to a clean and healthy environment;
  - Article 69: Obligation of the state in respect to the environment
  - Article 70: Environment and Land court
  - Article 232: Values and principles of public service
  - Article: 260: Definition of marginalized community
  - Chapter 6: Leadership and Integrity

Sustainable and productive management of land and land resources are enshrined in Chapter 5 of the Kenyan Constitution

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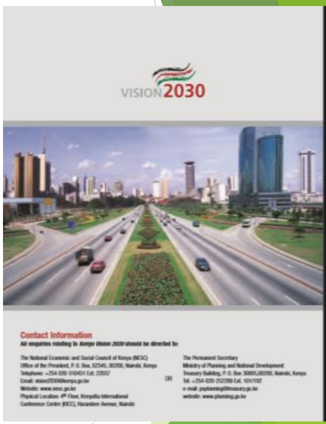
VISION 2030

- Vision 2030 aims to transform Kenya into "a newly industrialising, middle-income country providing a high quality of life to all its citizens in a clean and secure environment."
- Vision 2030 projects 10% economic growth and that 3% of that growth will be affected by climate change, hence limiting a double digit growth;
- The Vision 2030 is implemented through Medium Term Plans;
- Current: Third Medium Term Plan MTP3) in which climate change has been recognised as a thematic area;
- NCCAP is aligned to MTP 3 and CIDP2.



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4. NATIONAL CLIMATE CHANGE PLANS & POLICIES

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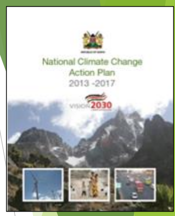
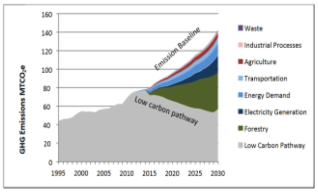
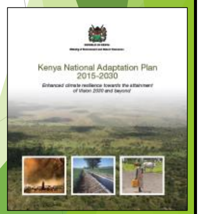
EXISTING CLIMATE CHANGE PLANS

- National Climate Change Response Strategy, 2010
- National Climate Change Action Plan, 2013-2017
- National Climate Change Action Plan, 2018-2022 (In progress)
- National Adaptation Plan, 2015-2030 (2018-2022 plan in progress)
- Green Economy Strategy and Implementation Plan (GESIP) 2016-2030
- Nationally Determined Contribution (NDC)







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Climate Change Policies

a) **National Climate Change Framework Policy**

- To enhance adaptive capacity & resilience to climate change and promote low carbon development for the sustainable development of Kenya- **mainstreaming of change**;
- Establish an **effective institutional framework** to, and mainstream climate change response into relevant sectors;

b) **Climate Finance Policy**

- Establishes the legal, institutional and reporting frameworks to access and manage climate finance;
- Goal of the Policy is to further Kenya's national development goals through enhanced mobilisation of climate finance that contributes to low carbon climate resilient development goals;
- Budget codes for tracking climate finance in place;
- National Climate Change Fund Regulations in progress

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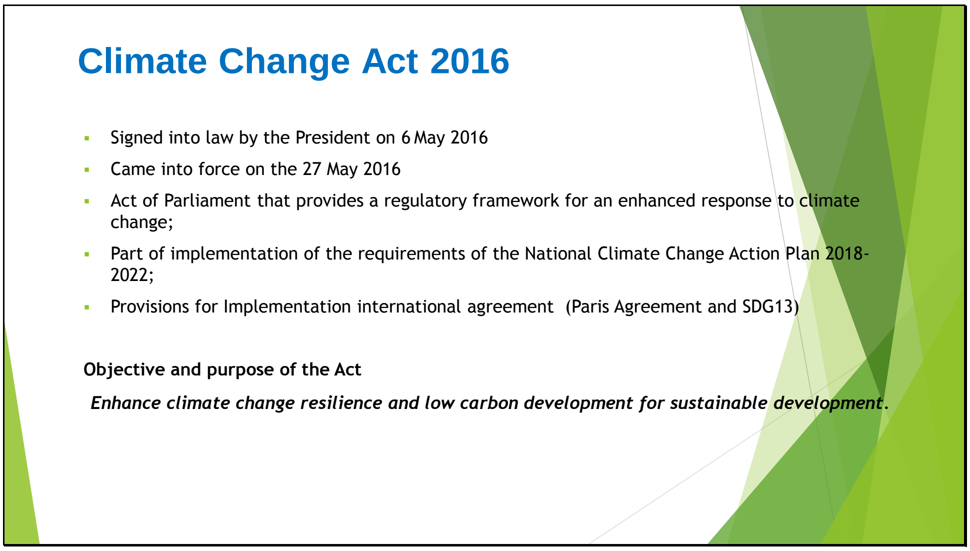

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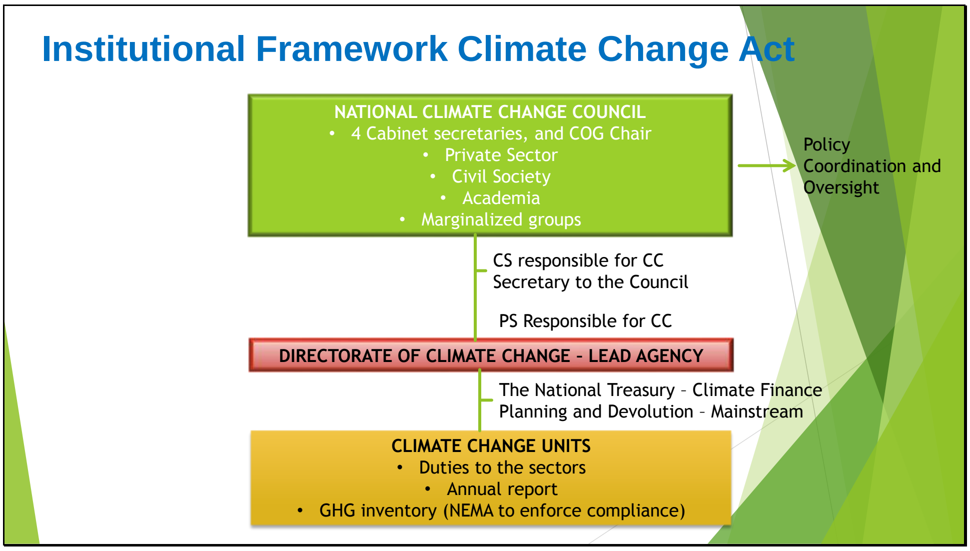

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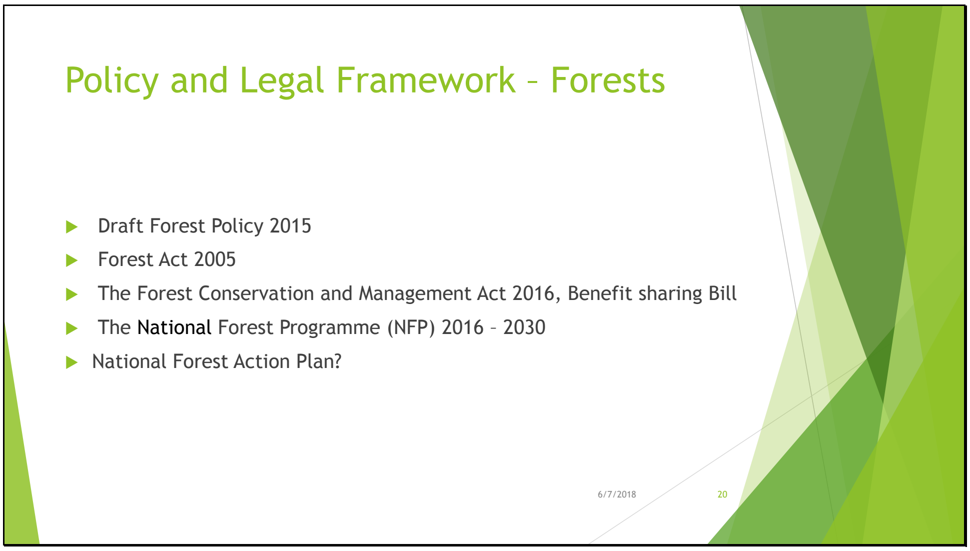

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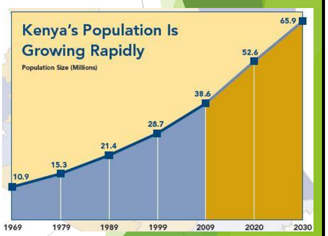
Slide 20

Kenya – Forests

- Status – about 7 % Tree Cover
- Sustainable and productive management of land and land resources are enshrined in Chapter 5 of the Kenyan Constitution
- Work to achieve and maintain a tree cover of at least 10% of total land area
- Forests support agriculture, fisheries, livestock, energy, wildlife, water, tourism, trade and industry that contribute between **33% to 39%** of the country's GDP.
- Forests contributed to 32 percent of emissions in 2015
- Drivers of deforestation and land degradation
  - Government has less authority to regulate land use on private lands
  - Biomass comprises about 80% of all energy used in the country;
  - High population growth rate;
  - Expanding agricultural activities;
  - Others



6/7/2018

Author: Kassim Agessa

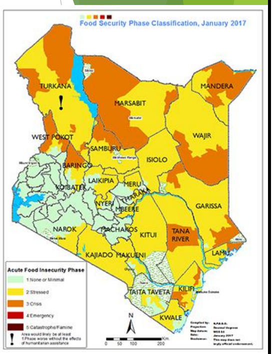
Slide 21

Effects of Deforestation

Effects of deforestation enhance vulnerability to climate change

- Loss of biodiversity
- Release of greenhouse gas emissions
- Soil erosion
- Floods
- Water scarcity due to destruction of water catchments
- Loss of **livelihoods**

Kajiado Floods.
Source: Standard Newspaper



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Source: UNICEF

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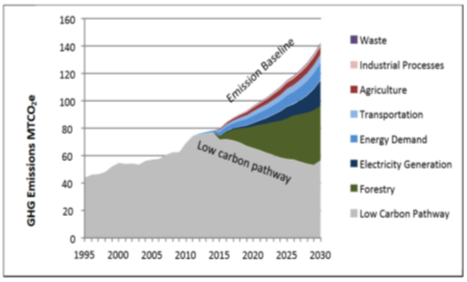
Kenya (I)NDC target



Composite abatement potential for all sectors for Kenya (technical potential) in MtCO2e
(Source: Second National Communication 2015)

- Kenya took a target of **30% abatement by 2030**
- From 6 sectors namely; energy, transport, industry, wastes, agriculture, forestry (carbon sinks) and adaptation actions in several sectors
- Kenya's projected emissions for 2030 are 143 MtCO2e/year.
- Technical emission reduction potential is 60%.
- The INDC/NDC mitigation target takes a conservative approach of half the potential which is equivalent to 43 MtCO2e /year hence the 30% abatement target.

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Summary - Mitigation contribution by NDC sector

	GHG Reduction Potential by 2030 in MtCO2e/year	
	Technical potential (60%)	**INDC Target (30%)**
Sector	**2030**	**2030**
Forestry	40.2	20.1
Power Generation	18.63	9.315
Transport	6.92	3.46
Energy Demand	12.17	6.085
Agriculture	5.53	2.765
Industrial processes	1.56	0.78
Waste	0.78	0.39
Total	85.79	42.895

Total Emissions in 2030 143 MtCO2e/year

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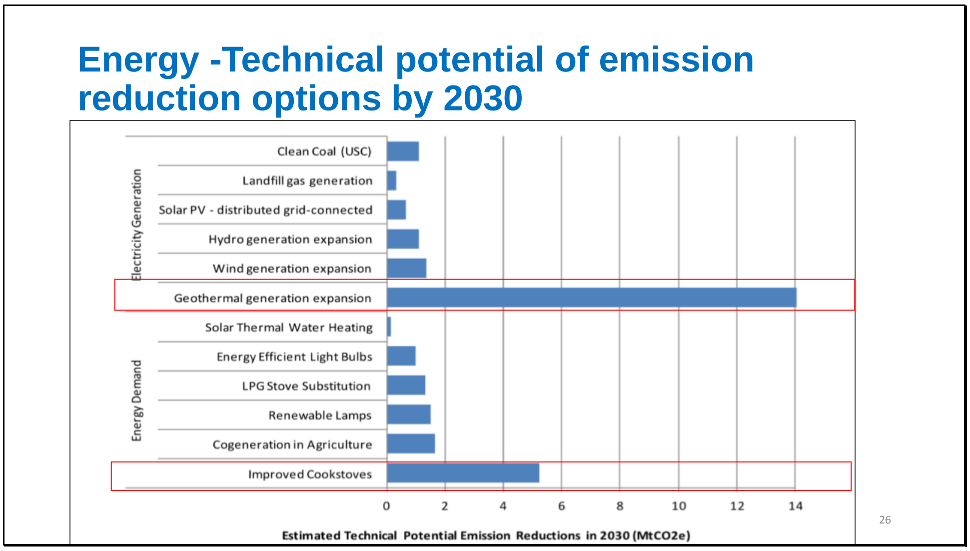

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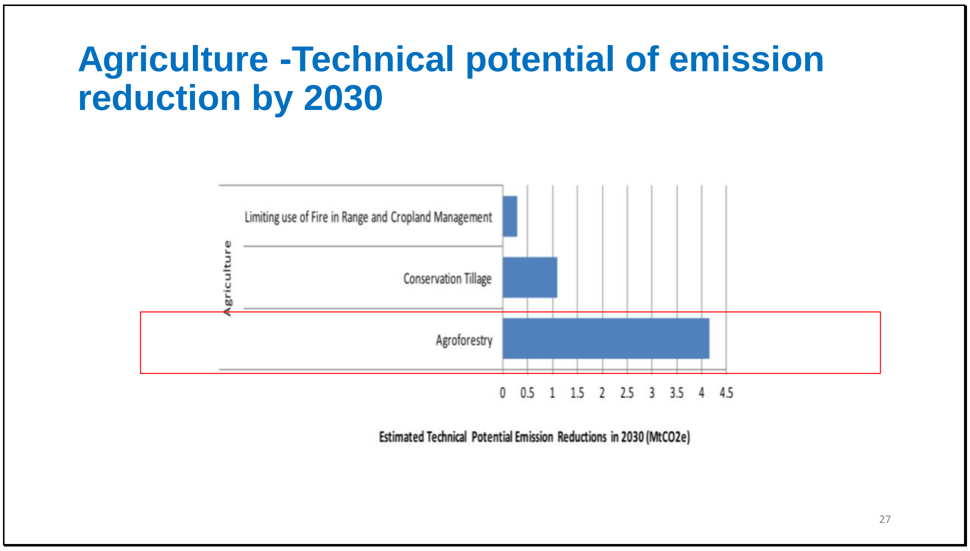

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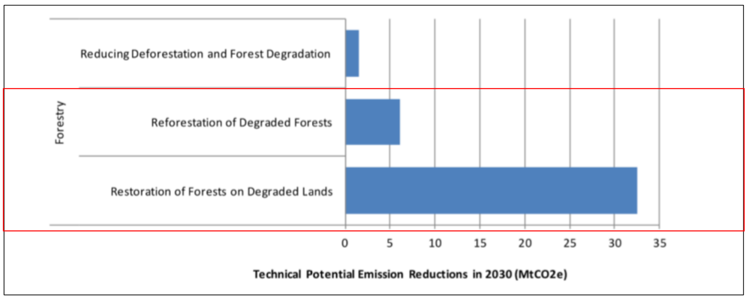
FORESTS -Technical potential of emission reduction options by 2030



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Adaptation

- Enhancing the conservation of biodiversity, and achieving other environmental as well as socio-economic benefits.
- Forestry adaptation actions can help to abate flooding and landslides.
- Restoring forests on degraded lands has the additional benefits of potentially increasing adaptive capacity in vulnerable areas such as mountain slopes, ASALs, and fragile ecosystems.
- The National Forest Programme (NFP) 2016 – 2030: identifies priority climate change interventions in the forestry sector and emphasises land-use planning, climate smart agriculture, and afforestation and reforestation actions

Slide 28

Other interventions

- Changing forest management: increasing carbon density at plot and landscape level
- Strong regulatory and institutional capacities
- Joint management agreements with communities
- Incentives for plantation establishment e.g. grants,
- Policies to increase substitution of forest-derived biofuels for fossil fuels and biomass for energy-intensive materials

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Thank You

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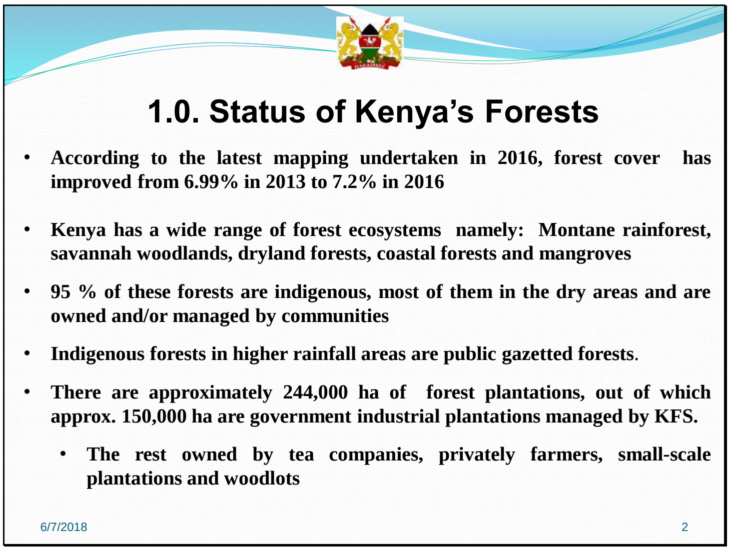
Status and Future Outlook of Forestry Development in Kenya

Keynote Presentation 3

Mr. Gideon Gathaara

Forest Conservation Secretary
Ministry of Environment and Forestry

Slide 1



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1.2. Forest categories in Kenya (MEWNR, 2013)

Forest category	Area (ha)	Role in wood product supply
Indigenous gazetted forests	905,000	Assigned for conservation, no commercial wood extraction allowed
Indigenous forest and woodlands on private and community land	3,347,000	Main source of wood energy and household construction wood
Government industrial plantations	149,900	Main source for forest industry
Private industrial plantations		Used for energy, to some extent used in forest industry
Private small-scale forest plantations and woodlots ("farm forestry")	94,000	Sources for household construction wood, poles and posts as well as energy. To some extent used in forest industry
Total	4,495,900	

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1.3. Status of Forests: Major Policy shifts

- **In 2002, the Government made radical policy shift and enacted the Forests Act (2005) which embraced the concept of Participatory Forest Management (PFM)**
- **The "Miti Mingi Maisha Bora – Supported the Forest Sector Reform in Kenya" (MMMB) Programme, 2009-2014, the operationalization of key reforms as provided for in the Forest Act 2005.**
- **Also supported the establishment of the KFS, the formation of CFAs and active engagement of the private sector.**

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1.3.1: Early successes from reforms

- **Reduction in illegal gazettment of forest land and enhanced community and private sector participation in forest management and utilisation**

- **Increased participation of local communities has resulted in enhanced contribution of forests to their livelihoods**

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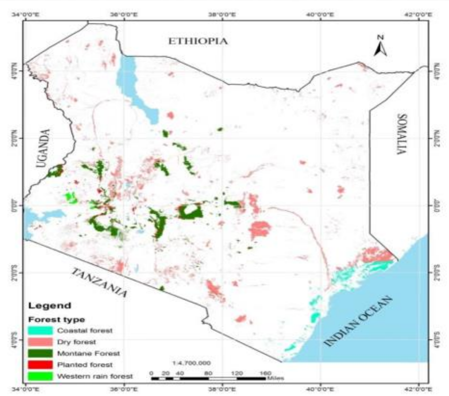
Forests in Kenya (NFP, 2016)



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1.5. Value of Forests

- **Forests have critical ecological, social, economic, cultural and spiritual functions**
- **Kenya is classified as mega diverse by UNEP's assessment whose forests have high species diversity and endemism.**
- **Forestry sector contributes 3.6% of the GDP excluding forestry's contribution to household wood energy, non-timber products and the vast value of ecosystem services (FAO's State of the World's Forest 2014)**
- **ESDA (2005) estimated that annual production of charcoal was 1.6 million tons; currently 2.5 million tons. The economic value of charcoal production over the same period grew from KSh 32 billion to KSh 135 billion**
- **Creapo Oy, (2014) estimated that the informal furniture industry is valued at about KSh 23 billion whereas the formal furniture industry is estimated at KSh 15 billion**

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1.5.1. Value of Forests contd…

- **A survey by Vomigal Ltd, found that NTFPs play important roles in the country's economy, generating about KSh 3.2 billion per year**
- **Major forest products are timber, poles and fuel wood and non-timber forest products which form substantial inputs to rural life and small-scale enterprises.**
- **Firewood meets over 64.5% of household energy needs while charcoal meets 7% (Weismann et al., 2014).**
- **Charcoal provides domestic energy for 82% of urban and 34% of rural households (Githiomi, 2012).**
- **Forest industry is a significant employer. KNBS, (2014 reports that;**
  - **26,371 persons employed in the sawmilling industry;**
  - **10,188 persons in furniture manufacturing**
  - **56,980 persons in pulp and paper.**
  - **700000 employed by the charcoal industry 700,000 people (MENR, 2013a)**

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1.6 Demand Drivers of Forest Products

- **The forest value chains are driven by a vibrant demand side fuelled by private consumption and construction**
- **There are two major drivers of wood consumption in Kenya:**
  - **Wood for energy and industrial wood products**
- **Sawn timber and wood panels are the main products of the wood processing industry in Kenya.**
  - **Demand for the domestic industry is higher than production. Consequently, the Country is a net-importer of both sawn timber and wood panels**
- **In terms of volumes, paper and paperboards have the highest consumption (see figure below).**
  - **However, domestic production is small and the majority of the consumption is covered by imports**
- **The country is also a net-importer of furniture and joinery.**

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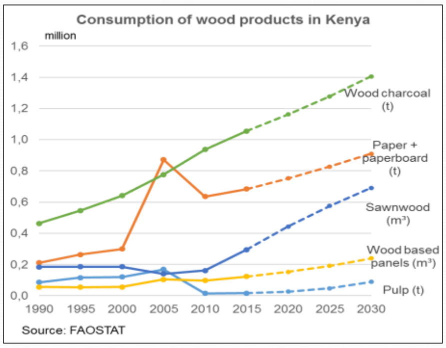
Consumption of Wood Products in Kenya



Development of trade balance for the main forest industry products in Kenya during the period 2000 – 2015 (FAO)

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1.6.1. Demand Drivers and Outlook of Consumption of Forest Products

- **Rapid population growth, urbanization and economic development, continue to increase consumption of forest products**
- **The structure and efficiency of the industry is at the moment not sufficient to fulfil the demand of industrial wood products**
- **Improvements, imports bills especially of paper products and wood based panels are likely to increase**
- **Furthermore, the growth in consumption of wood energy will put ever increasing pressure on the indigenous forests and woodlands**

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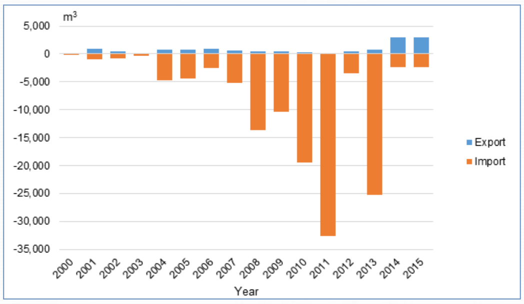
Trade Balance of Sawn Timber 2000 – 2015 (Source: FAO)



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1.7. New Private Sector Emerging in Forestry Sector

- **A 10 year logging ban was lifted 4 years ago, and a fairly short logging moratorium was declared in early 2015 and now 2018 which has slowed down growth of the sector**
- **So far about 200 saw millers have made investments in new technologies, mainly small band saws, thus improving the recovery rate.**
- **There are two categories of private sector in Forestry.**
  - **Big established companies such as Timsales, Comply and Raiply and**
  - **Growing smaller enterprises trying to find their way to markets.**
- **The aggressiveness of the smaller enterprises has the potential for a leapfrog progress in forest development, because there is a strong entrepreneurship culture in the country**

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1.8. Recent Reforms in the Forest Sector

- **By 1996, (22 years ago) forest resources were in a state of degradation**
- **Policy shifts by the government, are seeing recovery in forest area and is currently increasing**
- **With forest recovery, there is an opportunity to re-direct efforts towards more efficient utilization of plantation forests**
- **Links between the formal and informal sectors are very weak and initiatives that bridge the gap should be a priority**

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2.0. Forest Sector Policies and Legal Framework

Significant progress towards development of enabling legal frameworks for sustainable management of its forest resources.

Policies and legislations that influence private sector and forest management are:

- **Draft National Forest Policy, 2015**
- **Forest Conservation and Management Act, 2016**
- **National Forest Programme (NFP: 2016-2030)**
- **Environmental Management and Coordination Act (EMCA)**
- **Draft Private Forests Rules and Regulations**
- **Strategies and plans**
- **Private Partnerships Act, 2013**

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2.1. Forest sector and the devolved system of governance

- **The devolved system of governance has ushered in a new political and economic system**
- **Devolution is causing reforms in the forestry sector as some important functions have been handed over to County Governments.**
- **However, the capacities of CGs should be strengthened to enable them efficiently execute the devolved forestry functions**
- **Transfer of the devolved forestry functions is being effected through Transition Implementation Plans (TIPs) developed jointly by KFS and each of the 47 Counties.**
- **The TIPs specify the 21 devolved functions and the timelines for implementation which ranges from 3-5 years.**

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2.3. Forest Sector Institutional Framework

A range of institutions and organisations are directly involved in forest management and conservation of forests in Kenya:

- **The National institutions are the Ministry of Environment and Forestry (MoEF) and its SAGAs**
  - **Kenya Forest Service (KFS),**
  - **Kenya Wildlife Service (KWS),**
  - **Kenya Forestry Research Institute (KEFRI),**
  - **National Museums of Kenya**
  - **Kenya Water Tower Agency (KWTA)**
  - **National Environment Management Authority (NEMA) and others.**

- **MoEF provides an oversight role in national forest policy formulation and regulatory function of the sector**

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3.0. Forest Sector Outlook

Kenya's forest sector covers

1. **Forest resources management and harvesting and includes:**
   - **KFS plantations,**
   - **On farm forestry**
   - **Individual plantations**
   - **Small scale farms**
2. **Forest products processing and trade (Value Chain) and**
3. **The private sector.**
4. **Natural Forests Conservation**
5. **Ecotourism**
6. **Non-Timber Forest Products**

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3.1. KFS Plantations

Threat / problem	Solutions
• Due to un balanced age structure wood supply to industry and KFS revenue collection are likely to decrease considerably during the coming years which means that opportunities of SMEs to operate will deteriorate.	• Support KFS to prepare analysis and action plan to sort out problems; prepare new technical orders • Strengthen technical capacities of SMEs/ contractors in thinning; • Improve access to new integrated harvesting technologies; • Increase capacities/ technologies of SMEs to improve the recovery rate of the value chains;

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KFS Plantations Contd.

• Plantation management is weak with low productivity and less income opportunities in the future.	• Improve technical capacities of KFS, CFAs and SME contractors in plantation management;
• Decreasing areas of PELIS implies that impact of KFS plantation management on livelihoods improvements of the surrounding communities is diminishing.	• Increase alternative employment through increased volumes of plantation management (e.g. pruning, thinning etc.) and strengthen CFA business management capacities • Support CFAs in growing trees on their farms

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3.2: On-Farm Forestry

- **There is limited information available on the extent of on-farm forest resources in Kenya, but is roughly estimated at 95,000 ha.**
- **This includes both individual farm commercial forestry and private companies industrial plantations owned by tea- and other companies.**
- **It does not however include small-scale plantations (<half acre) or agroforestry of individual farmers.**

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3.3. Small Scale Farm Forest Resources

- **Tree growing on farms is widespread all over the country where there is favourable climate.**
- **The size of land set aside for tree growing depends on the size of the farm and the priorities of the farmer.**
- **Although income from selling trees is one driver for farm forestry, tree growers are not adequately linked into the timber value chain.**
- **The supply from farms is typically small volumes, low quality and with logistical challenges due to low quantities.**
- **These barriers limiting Forest Industries from sourcing their raw materials from small-scale tree growers.**

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3.4: Private Companies' Industrial Plantations

- **A number of tea and tobacco companies have established industrial plantations to secure their own supply of fuelwood.**
- **Some of them are also processing sawn timber and poles for their internal use and sale.**
- **Finlay's corporation manages 3,000 hectares of forest plantation to supply fuelwood for their five tea factories.**
- **Kenya Tea Development Agency (KTDA) has a land area of 13,880 ha of which 52% is forest plantations, and;**
- **Has set a target to secure 620 ha of land for each of its 65 factories.**

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4.0. Forest Products Processing and trade (Value Chain)

MENR (2013) reported that

- **The country has a wood supply potential of 31.4 million m^3 against a national demand of 41.7 million m^3, hence a deficit of 10.3 million m^3 in 2013.**
- **Forecasts for a 20 year period indicate a 20.0% increase in supply and 21.6% increase in demand of wood by the year 2032 which signifies a gradually *increasing deficit*.**
- **Main source of timber is the KFS plantations,**
- **Other associated value are sawn wood, panels and pulp and paper.**
- **Source of poles is a combination of KFS plantations, private company estates and farmlands.**
- **Wood fuel and charcoal are mainly sourced form farmland.**

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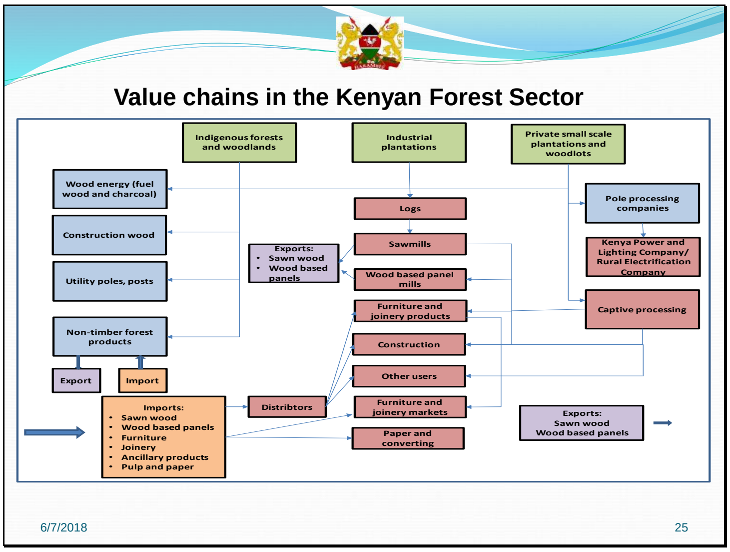

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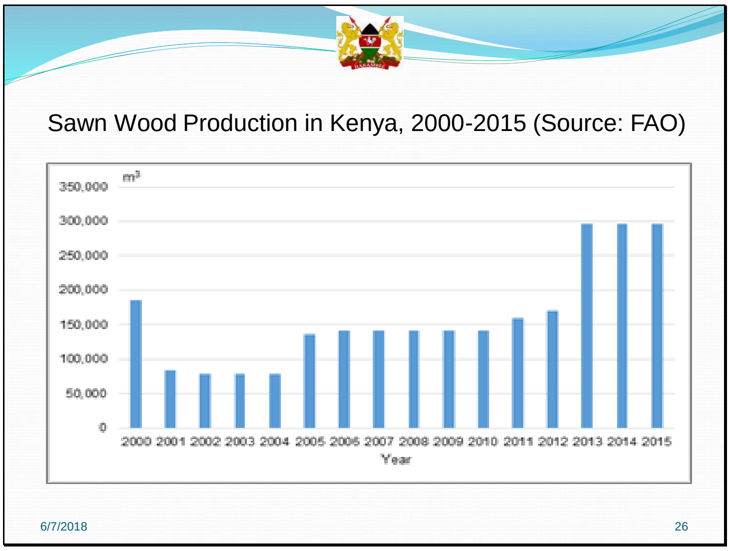

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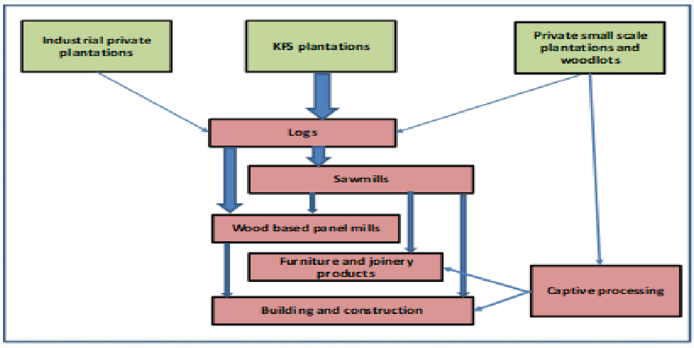
4.1. The Timber Value Chain



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4.2. The Wood Panel Value Chain

- **A big part of domestic consumption of wood panels is covered by imports**
- **Local production of wood based panels suffered a major setback in 2009 following the collapse of one of Kenya's biggest forest industries, the Pan Paper Mills in Webuye (Forencon, 2016)**
- **Production of wood panels, soft boards, fibre boards and chip boards in Kenya has been dominated by three companies; Comply, Raiply and Timsales**
- **Comply is the only producer of MDF in the country (Forencon, 2016)**
- **However, this situation is changing, with a number of sawmill owners investing in plywood plants.**

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3.3. Transmission Poles Value Chain

- **This includes transmission poles, construction poles and posts for domestic construction and fencing.**
- **Wooden transmission poles are almost exclusively from Eucalyptus mainly consumed by Kenya Power and Lightning Company (KPLC) and Rural Electrification Authority (REA).**
- **The estimated annual demand is 400,000 – 500,000 poles per year.**
- **The domestic supply of poles is enough to fulfil the demand. However, to some extent poles are also imported, e.g. KPLC is importing ~ 10 % of the company's requirement.**

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4.4. Pulp and Paper Value Chain

- **In the pulp and paper industry there are 5 small companies producing recycled fibre-based packaging grades and tissue (MMMB, 2013)**
- **At the moment there is no pulp and paper mill in the country utilizing wood as raw material**
- **The biggest mill, the Webuye Pulp and Paper Mill in Western Kenya, was closed in 2009, but has now been bought by an investor and one of its four processing lines is back to production of 'brown paper'. The mill is expected to be in full operation in 2 years**
- **The mill depended during its operations on raw material from KFS plantations and at the moment there are negotiations on-going for 25,000 ha of KFS plantations to be set aside to supply the mill**

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4.5. Fuel Wood Value Chain

- **There is a growing demand for industrial wood fuel due to the tea industry shifting from furnace oil and electricity in their drying processes**
- **This industrial firewood is sourced both from the companies' own plantations as well as from farms and KFS plantations.**
- **The price paid for fuel wood (800 – 2000 KSH per stack = 1 m^3) is lower than price paid for transmission poles**
- **Since not all logs qualify for transmission poles, it is critical to enhance the capacity of the tree growers on integrated harvesting (poles, wood fuel and sawn timber) to ensure optimal utilisation and value for money on investments**

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4.6. Status of Logging and Wood Processing Technology

Threat/Problem	Action
Poor quality of thinning	Development of thinning methods and training of chainsaw and machinery operators
Inappropriate machinery for thinning	Investment in appropriate technology for thinning
Little up-stream integration	Investment in technology that can enhance up-stream integration
Labour intensive and manual harvesting operations	Investments in cranes/ loaders and training of operators
Problems with work safety	Development of safety standards, purchase of equipment/devices, training and improved enforcement.

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5.0 Cross-cutting Issues in the Forest Sector

- **Forest Governance**
- **Human Rights**
- **Gender**
- **Climate Change**

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5.1. Forest Sector Donor Coordination

- **The Forestry Issue Group (FIG) was originally a coordination group of development partners but currently it brings together the Kenyan government and forest sector donors such as**
  - **The Embassy of Finland (as current chair),**
  - **Japan International Cooperation Agency,**
  - **World Bank, FAO,**
  - **United Nations Development programme, United Nations Environment Programme,**
  - **GIZ,**
  - **Department for International Development,**
  - **Gatsby Africa,**
  - **The European Union and other donors to coordinate their forest sector financing arrangements**
- **A reform with the objective to have FIG as a coordination group for all the stakeholders is ongoing**

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6. Conclusion and Way Forward

- Evidence of reforms in the forestry sector includes
  - The recent NFP,
  - Forest act and Forest Policy and the Government's continuing measures to improve the business environment.
- The population and the economy are growing rapidly and there is a construction boom leading to a growing deficit of timber, currently 10.3 million cubic meters.
- The Forest sector has a lot of potential to increase the total volume of production, improve the quality of products and introduce new products.
- To achieve this, there is a need to make appropriate investments throughout the whole forest value chains from plantation management to processing

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6.1. Conclusion and Way Forward contd…

- Forestry is a devolved function which means CGs will have a number of new functions despite their low capacities.
- It is KFS's responsibility by law to offer capacity building to CGs to enable them execute their mandates effectively.
- An emerging private sector is looking for increasing business opportunities. These should be analyzed and managed carefully in order to create a pragmatic model to work with.

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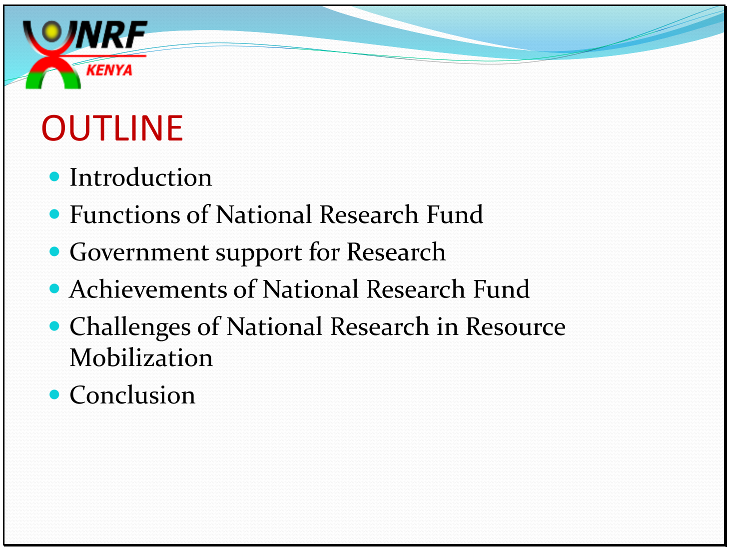
Challenges of National Research Fund in Resource Mobilization

Keynote Presentation 4

Dr. Roselida Owuor

Director, Research
National Research Fund - Kenya

Slide 1



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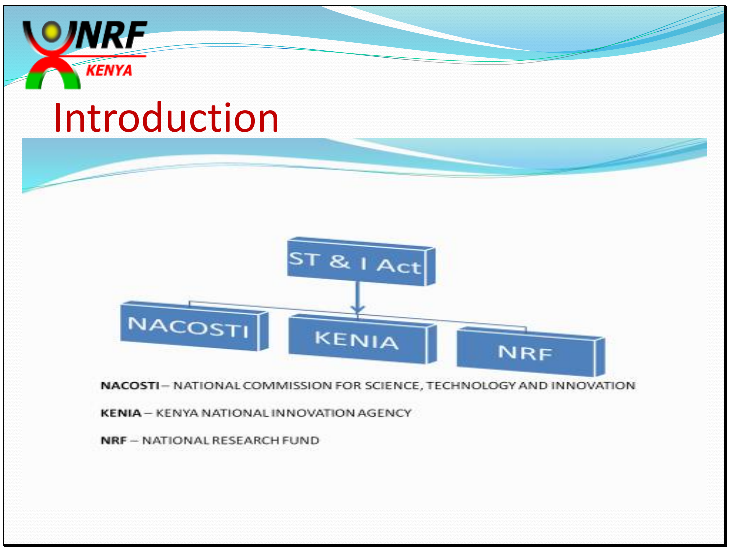

Slide 3

NRF KENYA

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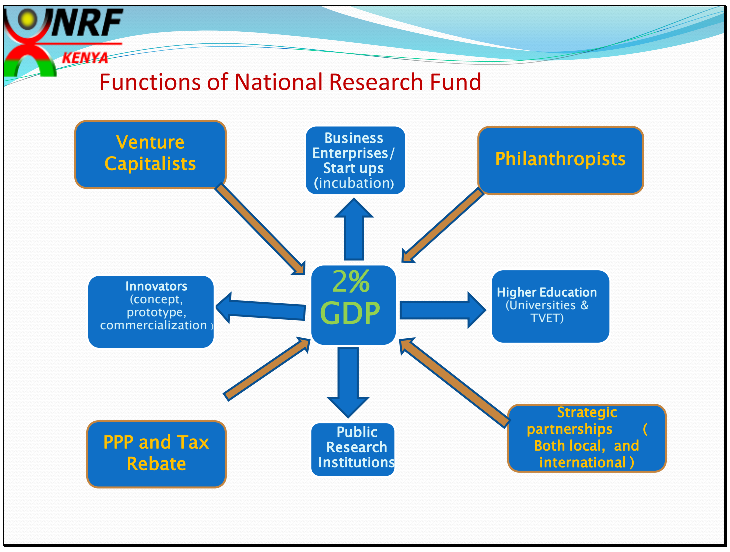
- NACOSTI: Advise, Regulation, coordination and promotion
- KENIA : Promotion and commercialization of innovations
- NRF: facilitate research for the advancement of science, technology and innovation

Slide 4



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NRF
KENYA

Cont.

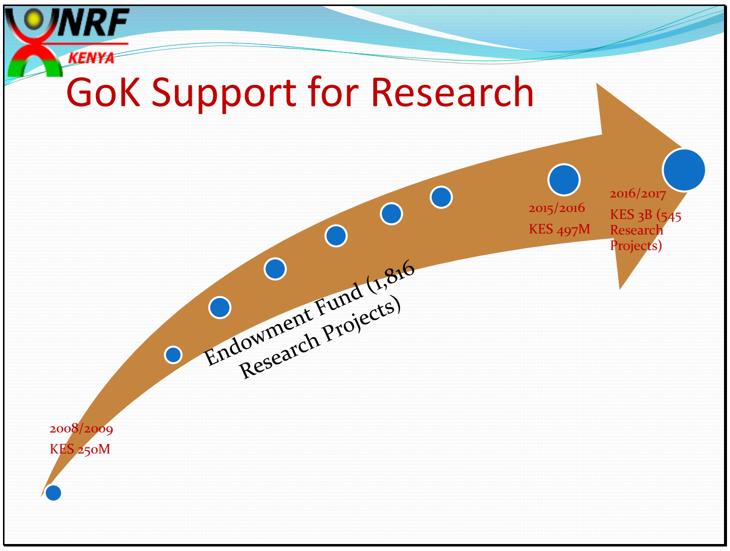
- manage and invest the funds so mobilized
- Support development of human resources
- Support the development of research capacities in the national priority areas of ST&I
- financial support for participation in international scientific activities through maintaining membership to appropriate international science organizations

Slide 6

Cont.

- evaluate the needs, status and results of research financed through the Fund
- initiate liaison with bodies involved in the protection of intellectual property rights
- compile and maintain a national database of research and innovation funded by the Fund and other agencies.

Slide 7



Slide 8

NRF KENYA

Cont.

Why multidisciplinary and multi-institutional research:

- Break silo mentality
- Promote public private partnership
- Share available research facilities
- Capacity building
- Enhance partnership

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NRF KENYA

Cont.

- Research to address national priority area
- Objectives to be SMART
- Budget to be aligned to the activities
- No administrative cost
- No payment of salaries
- No Lease of offices

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NRF KENYA

Achievements of National Research Fund

- Successfully mobilised resources in form of:
  - Government grant of Ksh 2.6 Billion
  - Development partners of about Ksh. 384 Million
- Funded various research Projects
- Established partnerships and collaborations
- Created awareness of the Fund by convening interactive fora to sensitize stakeholders

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NRF KENYA

Projects funded in 2016/2017 FY

Category	No.
Multidisciplinary and multi-institutional Research	158
PhD Projects	202
Msc./MA Projects	185
Infrastructure	21

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Bilateral and multilateral Programs 2016/2017 FY

Kenya-UK	No.	Institutions
Institutional Links Bilateral	5	UoN (2), KEMFRI, IDS
Researcher Link s Bilateral	3	UoN (2), JKUAT
Researcher Links Trilateral	3	KCA, MMUST, Moi Univ.
South Africa Funded		
Researcher Links Trilateral	3	JKUAT, Strathmore/ KEMRI, Agha Khan University

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Bilateral and multilateral Programs 2017/2018 FY

Category	Applications Reviewed	No of applications Shortlisted	Funded Projects
Institutional Links	48	14	8
Researcher Links Bi-lateral	13	6	2
Researcher Links Tri-lateral	5	1	1
Total	66	21	11

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NRF KENYA

Challenges of National Research in Resource Mobilization

- Changing priorities of development Partners
- Criteria used by development partners to evaluate proposals
- Conditions set by development partners
- Capacity limitation
- Competition among institutions in the same sector
- Natural calamities such as floods

Slide 15

Conclusion

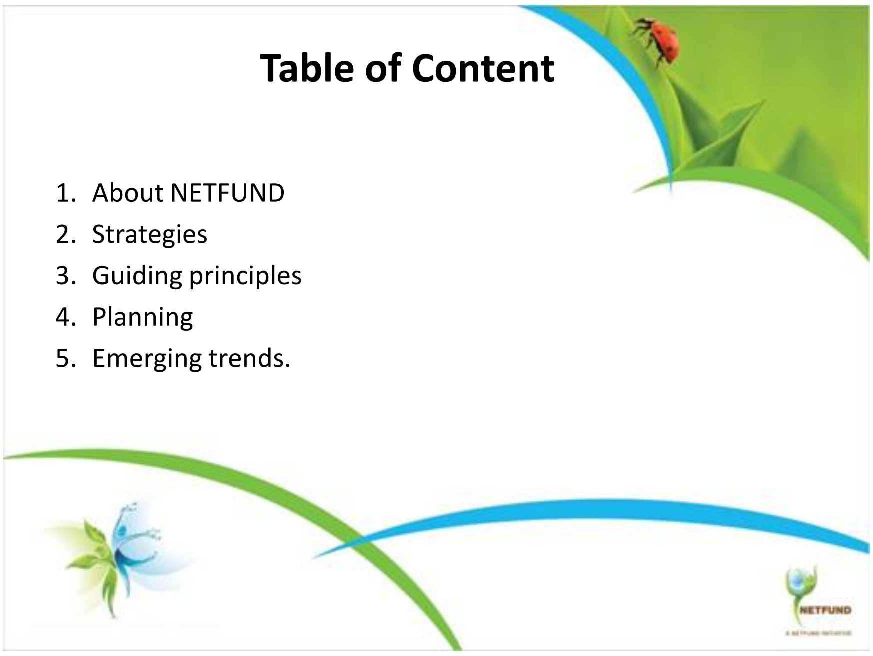
- Developing Resource Mobilization Strategy
- Considering resource mobilization from private sector
- Plans to enhance internal capacity
- Proposed Division for Resource mobilization

Planning, Strategies, and Emerging Trends on Resource Mobilization: NETFUND Experience

Keynote Presentation 5

Mary Kiai

Senior Manager, Resource Mobilization Department
National Environment Trust Fund (NETFUND)



About National Environment Trust Fund (NETFUND)

We are a state agency established under the Environment Management and Co-ordination Act (EMCA 1999) by the Ministry of Environment and Forestry.

NETFUND

Vision …

Is that of a society empowered and motivated to sustainability manage the environment

This vision draws from Kenya's development blue print the Vision 2030, whose social pillar advocates for "a just and cohesive society enjoying reputable social development in a clean and secure environment".

NETFUND

A NETFUND INITIATIVE

Green Innovation Awards.

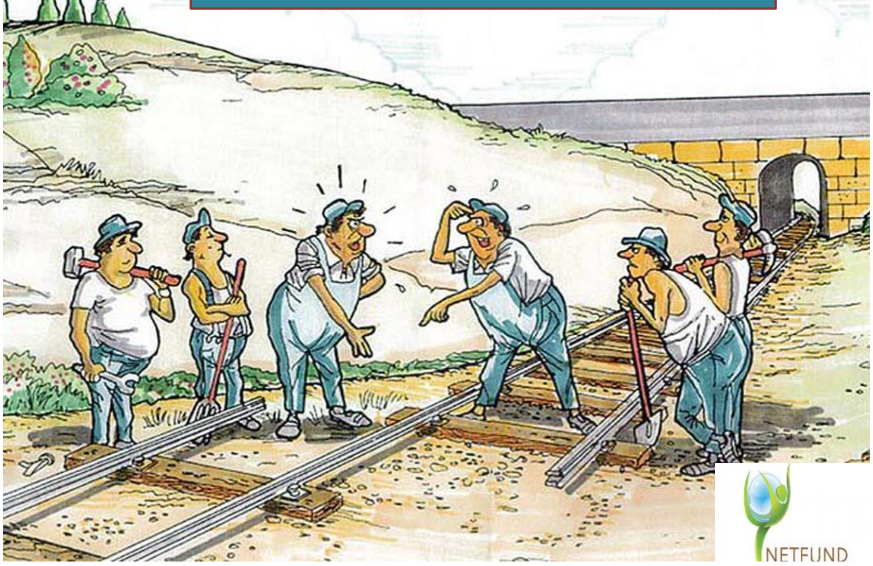
- The initiatives is geared towards realizing an environmentally responsible and motivated society embracing best practices for a clean, health and production environment while the mission is to promote self-regulation and best practices in environmental management.

Through

- Promoting a favorable environment for green growth initiatives
- Supporting the development of green enterprises through an incubation process.
- Public awareness on green innovations.

NETFUND

Strategy & Planning



NETFUND

Guiding principles in resource Mobilization

1) Team Work
2) Transparency and accountability
3) Partnerships
4) Due Diligence.

Resource Mobilization Strategy

Organization Strategy which broadly sets out the strategic directions (2015-2018).

RM strategy Provides :-

a) Strategic direction for effective project identification , proposal writing, resources mobilization and effective and efficient management of grant funded projects.

b) A set of principles and operation framework that guides NETFUND's resource mobilization principles whilst linking program design and program planning.

Our resource mobilization approaches.

- Solicited Prospect Research
- Unsolicited Prospect Research
- Concept Development

Proposal development process.

WINNING TEAM MODEL	
Red team	Team leader. Constitutes the concept/ proposal devpt team Take lead in drafting PCN/proposal
Grey team	Review proposal Provide technical input
Blue team	Final review and internal approval Submission and follow ups with donor

Grant management

- Project start-up/Inception meeting
- Ensuring contract compliance on budget, time and scope as per approved documents. As well as Public Finance Management Act, EMCA, Public Audit Act and Public Procurement and Disposal Act.
- Constant communication through out the project implementation cycle
- Project close out.

Emerging trends

- Due to impact of climate change there is increased national and international interest on environmental issues.
- Private sector integration of business sustainability models has created opportunities to support environmental projects among others.
- Development partners more interested in working with consortiums and partnerships as opposed to lone organizations.
- With the devolved governance structure there is more focus at County level.
- value for money and demonstration for high impact results by development partners.

Emerging trends…… continued

- Technological advancement, increased crowd funding platforms that transcend boundaries

Example…… B-BOX in partnership with Trine crowd funding, ventured into a Solar campaign. The crowd funding initiative allowed crowd-investor with as little as $ 25 to invest to support clean energy accessible. The Hub is in H/Bay and hopes to provide 30,000 households with solar energy in Homabay. Through the crowd platform fund they were able to raise US$ 1.8 million in just under a month).

NETFUND

Our Major Partners

HARAMBEE

INTERGOVERNMENTAL AUTHORITY ON DEVELOPMENT

IGAD

EMBASSY OF SWEDEN

SlovakAid

UN DP

Empowered lives. Resilient nations.

AFRICAN FUND FOR ENDANGERED WILDLIFE (KENYA) LTD.

nema

Bamburi cement

USAID FROM THE AMERICAN PEOPLE

WWF

Danish International Development Agency

The Nature Conservancy

Protecting nature. Preserving life.

UNEP

University of Nairobi

KCB Making the Difference

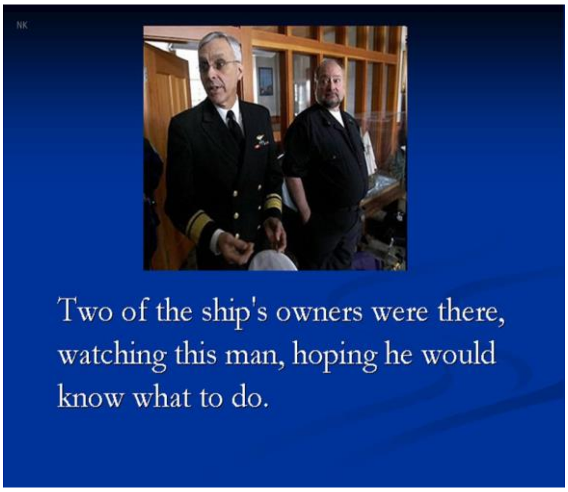
NETFUND

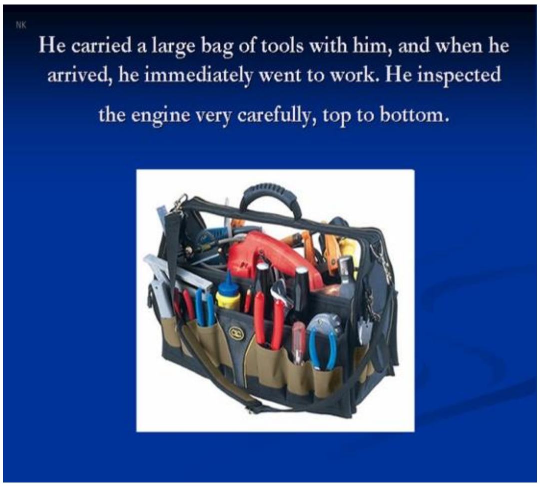
Lessons Learnt

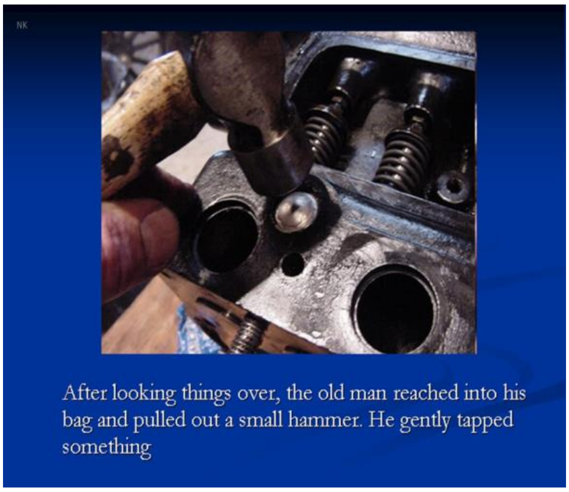
- Gathering intelligence is key for purposes of pre-positioning the organization way before the call for proposal is issued.
- Thorough understanding of the RFP, guidelines and selection criteria and scoring process is critical while developing the proposal.

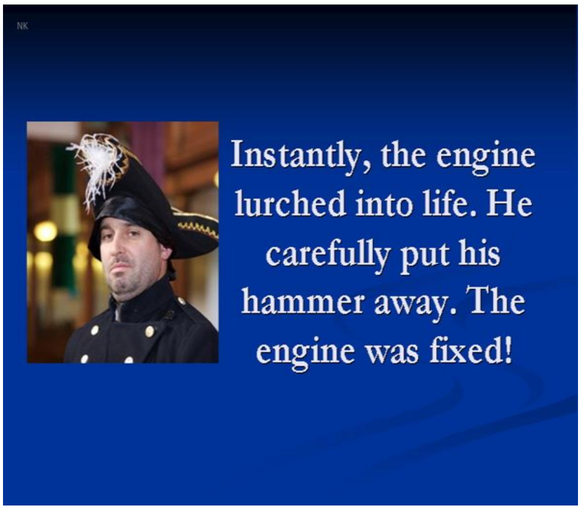

NK
The ship's owners tried one expert after another


NK
Then they brought in an old man who had
been fixing ships since he was a young

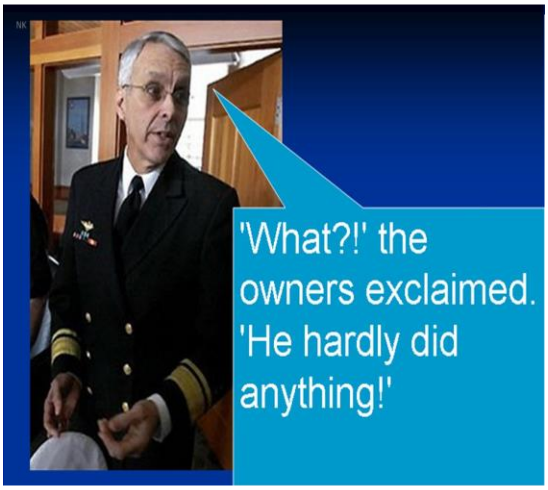

NK
Two of the ship's owners were there,
watching this man, hoping he would
know what to do.

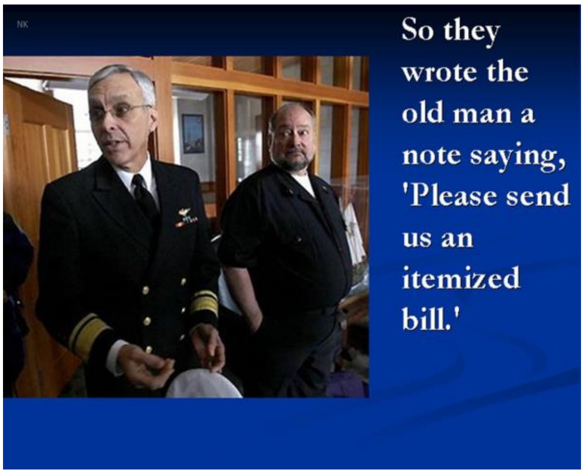

NK
He carried a large bag of tools with him, and when he
arrived, he immediately went to work. He inspected
the engine very carefully, top to bottom.

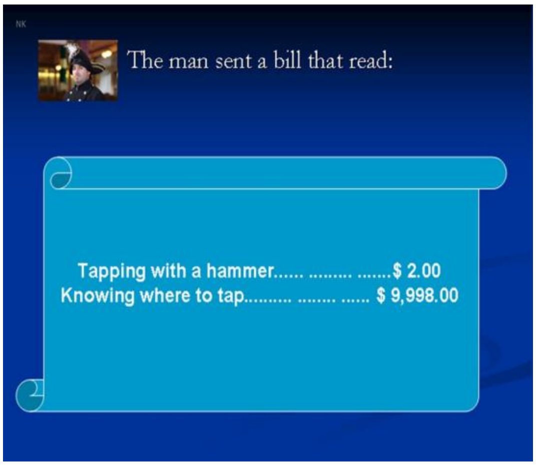

After looking things over, the old man reached into his bag and pulled out a small hammer. He gently tapped something


Instantly, the engine lurched into life. He carefully put his hammer away. The engine was fixed!


A week later, the owners received a bill from the old man for 10,000 Dollars


'What?!' the owners exclaimed. 'He hardly did anything!'


So they wrote the old man a note saying, 'Please send us an itemized bill.'


The man sent a bill that read:
Tapping with a hammer...... ....$ 2.00
Knowing where to tap.......... .... $ 9,998.00


Effort is important, but knowing where to make an effort makes all the difference!

Where to get us

National Water Conservation & Pipeline Corporation
New Building Complex, First Floor

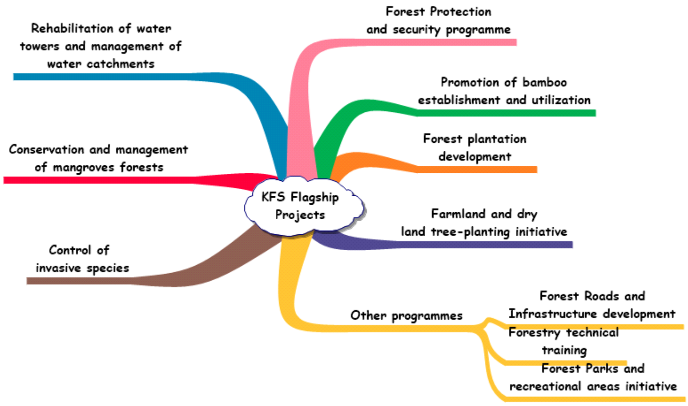
www.netfund.go .ke
NETFUNDKENYA
254 20 236 9563
National Environment Trust Fund Kenya

Kenya Forest Service Experience on Long-term Engagements with Development Partners: Case of Finnish Government

Keynote Presentation 6

Zipporah Chebett

Ag. Deputy Chief Conservator of Forests (Plantations and Enterprise)
Kenya Forest Service



3

Experiences on Engagement with Development Partners

Donor’s Engagement

Inception Phase

- •Idea
- •Concept Note
- •Project proposal
- •Project Agreement

Implementation Phase

- •Project Launch
- •Implementation
- • Medium Term Evaluation
- •Completion
- •Closure

- •Lessons learnt
- •Impact Evaluation
- •Synthesize new ideas

5

MINISTRY FOR FOREIGN AFFAIRS OF FINLAND

An Example of Donor’s Engagement

Finnish Support to Forestry Development in Kenya

KENYA Forest Service

12

KENYA
Forest Service

A history where one step builds into another

1) Finnish development assistance to Kenya started in 1960s and has been consistent over the years.
2) Kenya became a "Programme Country" in 1980s with *traceable* footprints - impacts
3) The Forest Industrial Training Centre (FITC) (1979-89) – Sawmilling development- over 10 years' commitment – *catalyst.*
4) Bura Fuelwood Plantation Project (1986-93).
5) Nakuru and Nyandarua Intensified Forestry Extension ('Miti Mingi Mashambani') Project (1990-95).

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KENYA
Forest Service

Cont'

•Kenya Forestry Master Plan Project (1991-95) – clear roadmap into the future with proposed major paradigm shifts. This resulted in the Forests Act, 2005; revised as Forest Conservation and Management Act, 2016 (MMMB), hence the continued reforms in the whole sector – *multiplier effect*.

•Kenya - Finland Forestry Programme (1996-1998), which expanded into other areas of forest development;

○*Institutional* strengthening, *Farm* forestry & *Indigenous* forests.

•MMMB – Support to Forest Sector Reforms in Kenya (2007 – 2016) – follow through!

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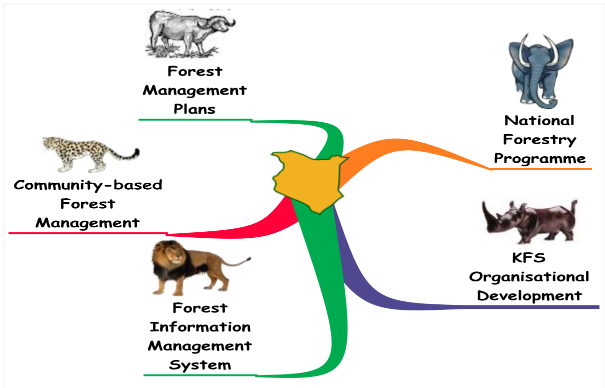
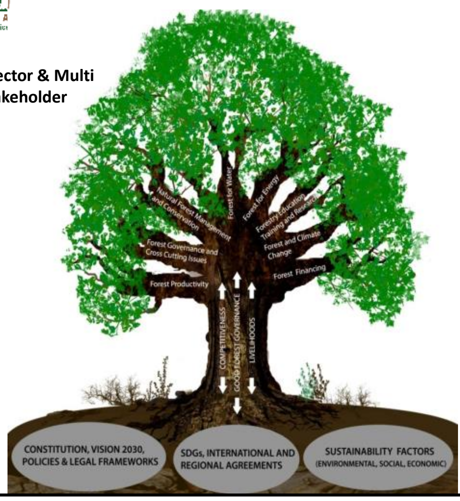
Mid-term Evaluation – Refocus on the Five high IMPACT areas



2016 – 2030: Forest Sector Development Framework
'THE ELEPHANT'

Multi sector & Multi stakeholder



16

Meeting of County Government & National policy makers during NFP validation workshop in Nakuru

17

The new KFS office block in Garissa

Involvement of communities in tree planting in Laikipia County

'THE RHINO'

18

Signing of "TIPs" between CCF and Governor, Laikipia County

'THE LEOPARD'

19

Plantation Forest & Tree Nursery Training Saw mill in KFC Londiani

'THE BUFFALO'

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Lessons Learnt

1. MMMB was a well-structured programme – though complex prompted reforms throughout the sector.
2. Reforms within the forest sector was well received and implemented – slow process that requires patience
3. PFM – is the way to go – the forest sector has many different stakeholders – communities, private sector and government (national and county governments) – MMMB worked in some pilot areas – others should be covered.
4. The use TA support improved capacity at all levels for knowledge transfer.
5. Enterprise development approach provides incentives for sustainable utilization of forest resources.
6. Communities in the ASALs have the ability to address their challenges – little support will do – just MAED.

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Long Live Kenya – Finland Friendship

At every stage, of the journey, there must be messages that encourage the heart!

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As we move on, let's Avoid Mistakes when Working with Development Partners

•Approach - NEGOTIATIONS.... NEGOGIATE CONTINUOUSLY.
•Deep understanding of the socio-economic and political situation of the development partner.
•There is need to for building personal relations with key characters in the negotiation.
•Do not try to look at everything from your own definition of what is rational and appropriate
•Dot not press a point if the other party is not prepared to readily accept it.

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Cont'

•Don't ask for concessions or compromises which are politically or culturally sensitive
•Do not stick to your Agenda if the other party has a different set of priorities
•Do not use jargon which can diffuse the other party
•Do not skip authority levels in a way that hurts middle level officials
•Don't ask for a decision when you know that the other party is not competent to say "yes" or "no"
•Do not look at things from your own narrow self interest.

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Profiles of Effective Negotiators

- Understands their objectives clearly
- Know what the other party wants and their viewpoints
- Plan and present facts effectively
- Use a mix of negotiation skills
- Maintain pressure but keep cool
- Are able to lead the team
- Change strategy whenever necessary
- Able to assess & handle situations tactfully
- Explore alternative courses of action
- Able to maintain good relations
- Able to make objective decisions
- Able to harness own resources

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Cont'

- Can visualize issues independently without failing to see the relationship between different issues
- Show flexibility
- Avoid negative reactions
- Able to offer counter proposals on the spot
- Are diplomatic enough to adjust to different styles
- Good strategist and tacticians (use both hard and soft approach)
- Know the strengths and weaknesses of their own and the other party
- Well prepared for the subject at hand

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CLOSING

SESSION

5th KEFRI Scientific Conference Highlights and how they Impact on the Government Big Four Agenda

Conference highlights

The theme of the 5th KEFRI Scientific Conference was 'Contribution of Forestry Research to Sustainable Development'. Conference participants were drawn from different backgrounds in the public and private sectors but with interest in forestry and the environment. Although majority of participants were from Kenya, there was representation from Uganda and Tanzania, making it a regional forum. Most of the participants were drawn from research organizations, universities, as well as decision-making authorities. The background of the participants ranged from scientists with long experience, practitioners in forestry, students pursuing post graduate studies and young scientists in early stages of their research careers. The Conference therefore enabled a diversified pool of participants to share experiences gained over time as stakeholders with interest and focus on forests and trees. The approach to hosting the Conference was in line with making forest science relevant to society, which the International Union of Forestry Research Organizations (IUFRO) highly recommends.

The pace of the Conference was set by two presentations that were made during the opening session; the opening address by Cabinet Secretary Ministry of Environment and Forestry, Mr. Keriako Tobiko and a keynote paper by Dr. Jeff A. Odera, Founding Director of KEFRI. So far reaching were implications of the presentations that Conference organizers and participants accommodated extra sessions in the programme to reflect upon the content of the keynote paper in shaping forestry research and also to ensure that forestry research, dissemination and partnership strategies developed for the period 2018 – 2022 also addressed the Big Four Development agenda of the Government of Kenya.

The Conference was arranged into themes as per KEFRI 5th Strategic Plan 2013 to 2018,. Each theme had a keynote address that highlighted pertinent forestry research and development issues. This was followed by presentations as per the Conference Programme (Annex I). At the close of each session, the stakeholders had a chance to interrogate the presentations and through plenary discussions provide additional perspectives. Presentations consisted of 62 oral papers and 18 posters. The following highlight the outcomes of the Conference.

1. Forestry research and development should be multidisciplinary for creation of synergies in research themes and efficient use of available resources including personnel, equipment, laboratories and research plots. Appropriate considerations should be made by KEFRI to help solve common problems in forestry and for wider dissemination of research findings. This will keep Kenya in the position of leadership in forestry research in the East African Region and beyond.

   Increased multi-disciplinary research should be guided by good research management; guarding of intellectual property rights; and regular monitoring, evaluation and audits on overall research performance, including tracer studies on technology adoption and impact. Scientists should also re-visit production and dissemination of forest technical and management orders to facilitate their implementation. A deliberate effort should be made to promote development and use of research protocols to enhance research replicability and upscaling of success stories.

2. Forestry research and development in biodiversity and environmental management should focus on the following key issues: Ecosystem-based monitoring with participatory scenario planning; farm forestry and social forestry technologies in biodiversity conservation and management; increasing tree cover; releasing pressure on natural forests resulting from requirements for energy, and other domestic and industrial uses; and replicate studies in all agro-ecological zones of the country in order to exploit the forestry potential and options especially in arid and semi-arid areas. Research in riparian and mangrove vegetation should also be prioritized especially with respect to regulatory services they provide, hence making a contribution to the blue economy. All this should be within gender and socio-economic considerations.

3. The main issues in forest productivity and improvement from the Conference sessions included: quality seed production, certification, distribution and marketing. Growing demand for certified seed for the establishment of industrial plantation and on-farm planting was noted and establishment of seed stands and seed orchards for quality seed production remains an important niche for KEFRI. Research in improvement of indigenous tree species was also highlighted with emphasis on continuous monitoring of trials and permanent sample plots (PSPs). There is also need to revamp research in forest genetics and tree breeding. Similarly, the forest seed value chain needs to be studied and appropriate recommendations made to improve on quality seed production, processing, storage and distribution. Acquisition and maintenance of seed handling equipment need to be prioritized and KEFRI should establish and where they exist, revamp regional research sub-centres and field stations in order to meet growing demand for tree seed. KEFRI should also consider enhancing distribution of quality tree seeds through privatization. However, the Institute must be in charge of certification and licensing of forest seed stockists and suppliers.

4. Discussions on Forest Products and Development revolved around research in: alternative green energy sources; efficiency in energy production and use; timber processing; bamboo products for use in housing, manufacturing and food security; neglected indigenous fruit tree species; promotion of non-timber forest products; and herbal medicinal plants. There is also great potential for Indigenous Knowledge Systems especially with respect to non-wood forest products.

5. In Socio-economics, Policy and Governance, there is need to develop equitable Payment for Ecosystem Services (PES) schemes to meet the International Panel on Climate Change (IPCC) guidelines in order to benefit from trade in ecosystem services provided by our conservation efforts. To achieve this, total economic valuation for ecosystem services

should be completed for the remaining forests and it is imperative that regulatory services of forests be studied when valuing the total contribution of the forestry sector in the national economy. So far, KEFRI has conducted total economic valuation for Mau, Cherangani and Mt. Elgon ecosystems. Proper valuation will determine contribution of forestry to Gross Domestic Product. Rehabilitation of degraded mangrove areas should also be included due to their potential in carbon emission capture. This will then emphasize the need for forestry research and subsequently, budgetary support. This component of forestry research will be the biggest pillar in support of the Government Big Four agenda.

6. Stakeholders in the forestry sector will need to create synergies in forestry research especially for cross cutting issues such as socio-economics, policy and governance, and climate change. The integration of Indigenous Knowledge Systems in formulation of ecosystem management plans, land tenure and property rights will be key to unlocking the potential of under-utilized and neglected forestry resources. Livelihood improvement schemes among pastoralists in ASALs and emerging forestry frontiers may be the golden key to unlock the potential of forestry in marginalized areas. There is constant need to review, monitor and evaluate forest governance at local levels through CFAs and other actors, and build their capacity in forest management. The need for mutual relationship between stakeholders in the forestry sector was emphasized.

7. In order to foster collaborative management of forests, knowledge management and partnerships was isolated as critical for forestry research and management. Areas of focus include: strengthening the capacity of counties for forestry extension services; establishment of demonstration plots; holding of field days; development of an efficient and effective research communication strategy; training needs assessment; packaging forestry as a viable investment; subsidiary legislation for implementation of Public Private Partnerships (PPPs); and enhancing collaboration with other institutions.

8. Decisions in forestry should be based on facts and science. Research in policy, governance and institutional framework should inform forestry impacting decisions by national and county governments. Hence, the need to strengthen linkage of research and policy.

The Government Big Four Agenda and Role of Forestry Research and Development

The Government Big Four agenda aims at enabling Kenyans meet their basic needs. Implementation of the Big Four agenda is expected to transform the level of Kenyans from that of hardship and want, to new lives of greater comfort and well-being. The four agenda are:

1. Food and nutritional security – Never again should we allow vagaries of weather to hold us hostage. Thus, the agenda aims at ensuring food production is not dictated by weather patterns. Government is to invest heavily in securing water tower and river ecosystems to harvest and sustainably exploit potential of ground water. The Government is also to address distribution, wastage, storage and value addition of agriculture commodities.
2. Affordable housing – Create 500,000 through finalization of affordable housing and home ownership scheme.
3. Enhancing Manufacturing – Grow manufacturing share from 5 to 15% by reducing power tariff charged by 50% between 10pm and 6am thus supporting 24 hour economy
4. Universal healthcare – Target 100% of health coverage for all households

The Conference synthesized the technologies developed from forestry research and how they can be leveraged upon to deliver the Government Big Four developmental agenda. The technologies and information generated in respect to each of the agenda is summarized below:

Technologies and information to impact on agenda on food and nutritional security:

The following presentations at the Conference highlighted how forestry contributes to food security mainly through; soil fertility improvement, added fodder supply, incentives such as PES, irrigation water, weed control, and pest and disease control:

- Adoption of fodder from Calliandra by 86 % of farmers in Embu County: The fodder is fed to dairy animals as a protein supplement, thus reducing cost of purchasing commercial concentrates by resource poor farmers and increasing milk production
- Improving agro-forestry practices and use of nitrogen fixing trees such as Casuarina: Leads to improved soil fertility and consequently increased food production
- Use of biochar from sugar bagasse: Biochar improves retention of soil nutrients and moisture, and accumulation of soil organic matter, hence improving crop productivity
- Use of plant residues such as maize stover as alternative sources of fertilizers: This increases crop yields under agroforestry systems for resource poor farmers
- Valuation of ecosystem services from the forest in the water towers: These forests contribute to supporting agricultural systems including value of forests in pollination
- Enhancing management of Forest Plantation Establishment and Livelihood Improvement Scheme (PELIS): PELIS contributes to establishment of forest plantations and to food security.

- Developing frameworks for Payment for Environmental Services (PES) that plough back incentives to producers of PES. The incentives aim at encouraging adoption of friendly practices for enhanced conservation of water towers and riparian areas. Improved conservation practices will lead to improved farm production
- Promotion of on-farm tree planting: to provide diversified income sources for households that can hence be used to purchase food
- Promotion of utilization of Prosopsis: to reduce its invasiveness and competition with food crops and pasture, while its pods are used as animal feed
- Use of mathematical models to study trends of invasive plant species: Invasive species affect productivity of farmlands and so understanding their population structure contributes to developing strategies for their control.
- Promotion of Non-Timber Forest Products (NTFPs): as food and additives in the food industry
- Increasing food sources from wild fruit tree species through domestication, conservation and sustainable utilization
- Enhancing productivity of coconut which has potential to substitute 30% of edible oil imports into the country
- Improving avocado productivity through enhanced pollination
- Application of Calliandra tree biomass as an organic fertilizer to reduce striga weed infestation and subsequently increase crop yields. Striga weed reduces farm productivity by up to 50%.
- Liming to reduce soil acidity hence enhancing fertilizer use efficiency by crops and consequently increasing agricultural productivity
- Promoting conservation of biodiversity in drylands resulting in healthy bee colonies which are important in pollinating agricultural food crops and honey production for increased food security
- Protection of mangroves that are important as breeding grounds and a healthy habitat for fish populations at the Kenyan coast.

Technologies and information to impact on agenda on affordable housing:

Presentations at the Conference highlighted technologies and information on tree establishment, utilization, quality control, and cost of materials for housing construction included:

- Cost benefit analysis of on-farm tree planting: Trees on-farm produce materials for housing construction
- Market and price trends of wood and other forest products: Prices affect cost of housing
- Appropriate forest plantation establishment methods enhances supply of wood thus contribute materials for housing
- Utilization of Prosopis for production of poles for low cost housing
- Products from trees in agroforestry systems such as timber and poles are used for housing construction

- Options for enhancing productivity of forests for increased supply of wood for construction of affordable houses
- Information on defects in plantation softwood in Kenya: causes, extent and distribution to offer high quality construction material
- Options for bamboo development in Kenya for affordable building materials

Technologies and information to impact on agenda on manufacturing:

The following presentations at the Conference offered a range of opportunities the country can exploit including technologies that will sustain provision of raw materials to respective manufacturing industries such as; wood and timber industries; food and beverage industries, pharmaceutical and cosmetic industries, paint manufacturers, and other indirect support to manufacturing through generation of clean affordable electricity:

- Information on prices of forest products contribute to manufacturing by adding value to forest products through timber sawing and charcoal production as well as other technologies
- Improved Earth and Casamance kilns for enhanced efficiency in charcoal production
- Production of charcoal briquettes from sugarcane bagasse
- Piloting biomass energy audit for energy conservation in Homa-Bay County, Kenya
- Well managed water towers will provide reliable water for agricultural production, generation of electricity, and manufacturing.
- Improved water quality enhances manufacturing due to reliable water supply for manufacturing and electricity generation
- Reduction of invasiveness by Prosopis will lead to establishment of more trees for the timber industry, while Prosopis pods are used in production of animal feeds
- Increased production of NTFPs will support manufacturing as some of these products are used in food processing and as food
- Forest plantations are a source of wood products used in manufacturing timber products used in furniture, construction of houses, and paper production
- Development and knowledge on performance of pine species and hybrids suitable for growing in Kenya diversifies plantation tree species, which are useful in the construction industry as well as for pulp and paper production
- Technologies on estimation of volume and biomass of commercial species are vital in projecting the productivity of important commercial tree species such as eucalypts whose products are used in construction industry, and as wood energy in processing industries
- Seed storage technologies are essential in ensuring that there is sustainable provision of viable seeds for planting trees, which have multiple uses in the construction industry.
- Trees such as Melia grown in the drylands are used in construction industry in these areas, hence understanding their sivicultural management ensures that there is sustainable high quality timber supply

- Growing of trees such as Casuarina and Melia in agroforestry systems ensures a sustainable supply of raw materials for construction and furniture industry
- Integrated pest management ensures healthy trees for use in construction, energy, pharmaceutical and manufacturing sectors, and avoids large losses on commercial tree species
- The technology on post-harvest handling of Sandalwood seeds is important in ensuring that there is sustainable supply of propagation material for large scale planting of the species for use in cosmetic and pharmaceutical industries
- Improved propagation of tree species such as Jojoba increases the supply of planting materials for plantation establishment in semi-arid areas. Jojoba is used in cosmetics, lubricant and pharmaceutical industries.
- Knowledge on pollinator diversity and activity contributes directly to the productivity of fruit trees such as avocado. The avocado tree provides raw materials for the food and cosmetic industries.

Technologies and information to impact on agenda on universal health care:

The Conference highlighted options for environmental conservation, which is the basis for a healthy population through ensuring a healthy environment and sustainable supply of raw materials that are used in manufacturing of pharmaceuticals. The following presentations supported universal health care:

- Well managed natural forests in the water towers and establishment of herbal groves will lead to sustainable provision of medicinal plants
- Improved water quality for consumption reduces water borne disease
- Use of traditional knowledge to enhance ecosystems and human health through use of traditional knowledge
- Appreciation of community perception to ecosystem services leads to improved health of the ecosystem for betterment of human health
- Promoting domestication of *Prunus africana* will lead to raw materials for production of traditional and modern medicine that will contribute to improved health of Kenyans
- Optimization of piperine extraction from *Piper nigrum* using different solvents for management of bedbugs
- Income from on-farm tree planting to enhance livelihood that could be used in healthcare insurance and supports wellness.

A detailed analysis of all presentations made during the Conference indicating the technology or information, and how it can be deployed to support the Government Big Four agenda are provided in Annex III of these Proceedings.

Speech by The Principal Secretary Ministry of Environemt and Forestry, Mr. Charles Sunkuli (CBS) During the Closing Ceremony of 5th KEFRI Scientific Conference at KEFRI Headquarters, Nairobi - Kenya, 19th April 2018

The Chairman KEFRI Board of Directors, Mr. Robinson Ng'ethe
Acting Director KEFRI, Dr. Jane Njuguna
Development Partners - EU, JICA, NRF, JIZ and UNEP
Collaborating institutions - KFS, NETFUND, SIFOR, SEKU and UoN
Retired former Directors of KEFRI
Distinguished guests
Invited guests
Ladies and gentlemen

It gives me great pleasure to grace this closing ceremony of 5th KEFRI Scientific Conference whose theme was "Contribution of Forestry Research to Sustainabile Development".

We note that over the years KEFRI in partnership with collaborating institutions has undertaken research in forestry and allied natural resources in various agro-ecological zones including arid areas.

The major output of research is technology development and information. These technologies and information have contributed significantly to forestry development in our country, including support in achieving the 10 percent tree cover as stipulated in Kenya Constitution 2010, and Vision 2030. Further, the technologies and information have been packaged in various forms including; publications, field days, demonstration plots, conferences, and mass media for dissemination and subsequent adoption by various stakeholders. The information disseminated has been instrumental in guiding forestry development and production including: species-site matching especially for the case of eucalyptus which presents a dilemma due to varying opinions by different stakeholders; quality seed production; management of natural resources; Payment for Ecosystem Services; carbon trade; wood processing; as well as value addition to non-wood forest products such as aloe, gums, resins, herbal medicine, honey and fruits for livelihood improvement.

I am also aware that KEFRI and collaborators have effectively shared information on afforestation and reforestation technologies, which have significantly contributed to increasing the country's forest cover from 2.9 percent a decade ago to the current 7.4 percent of Kenya's total land mass. This is in addition to providing valuable information that has informed policy, programmes, strategic action and decisions in forestry sector development.

I am gratified that the Conference participants were drawn from major institution involved in forest development and environment conservation.

I also note with appreciation the participation of scientists from the neighbouring countries of Tanzania and Uganda. I note and appreciate the comments by Director of Research, National Forestry Resources Research Institute, Uganda who acknowledged Kenya's leadership in forestry research. I would also like to emphasize that Kenya's success is success for East African Community and also for the continent at large. This exchange of knowledge and information is invaluable, as we share cross-border resources, culture, and vision.

Ladies and gentlemen,
I am informed that the Conference presentations included about 76 papers, and participants discussed topical issues on challenges and opportunities in tree and forest establishment, protection, rehabilitation, management, conservation and sustainable utilization in our various landscapes. The Conference also covered knowledge management, and resource mobilization strategies for optimal impact on adoption of technologies. I believe that through these presentations and discussions, the participants had access to the new technologies and information that are vital to the enhanced and sustainable forestry development and management, as well as environmental conservation.

My Ministry has contributed to this Conference through provision of necessary resources. Ladies and gentlemen, I assure you that the Ministry shall continue supporting KEFRI and collaborators by providing the enabling policies and a conducive working environment for research and development. I urge scientists to double their efforts in knowledge development, information sharing and transfer of developed technologies through training with the aim of enhancing the users' knowledge on tree farming as a sustainable enterprise.

In conclusion I trust that experiences that have been shared in this Conference will be of great benefit to you and millions of Kenyans, our neighbours, and the human community, which we clearly serve through our endeavours.

I thank the Chairman of KEFRI Board of Directors, the Board of Directors, the Acting Director of KEFRI, the National Research Fund, participants and the Conference Organising Committee for making the 5th KEFRI Scientific Conference a great success.

Ladies and gentlemen
It is now my humble pleasure and duty to declare this Conference officially closed, even though not permanently, because this is a continuous process that we need to re-visit based on deliberations during the Conference and proposed actions with respect to implementation of the Government Big Four agenda.

With that, I thank the Almighty for giving us this opportunity to paricipate in the Conference and have a fruitful ending.

Thank you so very much.

ANNEXES

Annex I: CONFERENCE PROGRAMME:

Day 1: Tuesday, 17th April 2018
SESSION I: Opening Plenary

Venue: Auditorium
Chairperson: Director, KEFRI
Rapporteurs: Mr. Albert Luvanda & Dr. George Muthike

Time (hrs)	Activity	
0830	Registration	
0900	Welcome Remarks/Introductions	
	Keynote Paper No. 1: Achievements, challenges and opportunities in research in forestry and allied natural resources in Kenya **Dr. Jeff A. Odera** Founding Director of KEFRI (1986 - 1995)	
	Official opening :	**Chief Guest : Mr. Keriako Tobiko** (CBS, SC) Cabinet Secretary, Ministry of Environment and Forestry
1030	***HEALTH BREAK***	

SESSION II: Parallel Sessions

	Biodiversity and Environment Management (BEM) *Venue:* Auditorium *Chair:* **Dr. Mwangi Kinyanjui-Karatina University** *Rapporteurs:* **Ms Margaret Kaigongi & Mr. Simon Wairungu**	**Socio-Economics, Policy and Governance (SPG)** *Venue:* **Bamboo Room** *Chair:* **Dr. Esther Mwangi,** CIFOR *Rapporteurs:* **Ms Roxventa Othim & Dr. David Langat**
1100	Benchmarking edaphic properties of Arabuko Sokoke forest for long-term biodiversity monitoring. ***Riziki Mwadalu***	On-farm tree growing opportunities and constraints in Murang'a County, Kenya. ***Peter Gachie***
1115	Water quality status in Mt. Elgon and Cherangany forested ecosystems. ***Stanley Nadir***	Adoption of *Calliandra calothyrsus* for improved dairy production in Embu County, Kenya. ***Paul Tuwei***
1130	Population structure of *Prunus africana* (HOOK f.) Kalkm and *Olea europaea* L. in South Nandi Afromontane forest, Kenya. ***Eric Abungu***	Gender related aspects in adoption of biomass energy conservation technologies in four selected areas of Kitui, County. ***Emily Kitheka***
1145	Evidence of genetic diversity and taxonomic differentiation among *Acacia senegal* populations and varieties in Kenys based on RAPD molecular markers. ***Stephen Omondi***	Status and growth determinants of non-timber forest products firms in Kenya. ***Linus Wekesa***
1200	Anthropogenic influences on species composition, richness and diversity in Museve and Mutuluni dryland forest fragments, Kitui, Kenya. ***Joshua Musau***	Management of *Prosopis juliflora* invasion in Baringo County through utilization. ***Paul Tuwei***

1215	Interactions between native tree species and environmental variables along forest edge-interior gradient in fragmented forest patches of Taita Hills, Kenya. ***Chemuku Wekesa***	Cost-benefit analysis of agroforestry technologies in semi-arid regions of West-Pokot County, Kenya. ***Brexidis Mandila***
1230	**Discussions**	**Discussions**
1300	***LUNCH***	

SESSION III: Parallel Sessions

	Biodiversity and Environment Management (BEM) *Venue:* **Auditorium** *Chair:* **Dr. Gabriel Muturi**, KEFRI *Rapporteurs:* **Mr. Stephen Kiama & Selestine Ingutia, KEFRI**	**Socio-Economics, Policy and Governance (SPG)** *Venue:* **Bamboo Room** *Chair:* **Dr. Joshua Cheboiwo**, KEFRI *Rapporteurs:* **Ms Stella Gatama & Mr. Tito Mbuvi**
1400	Effect of water conservation method on the yield of coconuts. ***Finyange Pole***	Markets and price trends for key tradable forest products in Kenya from 1999-2014. ***Jonah Kiprop***
1415	Linking different levels of forest degradation to suitable forest restoration techniques in selected forests in western Kenya. ***John Otuoma***	Financial assessment of woodlots on smallholdings in coast of Kenya. ***Linus Wekesa***
1430	The fate of Taita Hills' forest fragments: Evaluation of forest cover change between 1973 and 2016 using Landsat imagery. ***Chemuku Wekesa***	Value of pollination services in farmlands adjacent to Mau, Cherangany and Mt. Elgon forests. ***Jonah Kiprop***
1445	**Discussions**	The value of Forest Ecosystem services of Mau complex, Cherangany and Mt. Elgon, Kenya. ***David Langat***
1500	Land cover changes in the Malewa River Basin, Kenya. ***Musa Cheruiyot***	Evaluating willingness to pay for watershed protection in Ndaka-ini dam, Murang'a County, Kenya. ***Joram Kagombe***
1515	Destruction of watershed forests beyond trees: Effects of anthropogenic disturbance on forest herpetofauna of Cherangany Hills Forest. ***John Opiyo***	From the wild to markets and farmlands: Plant species in biotrade. ***Agnes Lusweti***
1530	**Discussions**	Participatory forest management: A case of equity in the forest plantation establishment and livelihood improvement scheme in Gathiuru and Hombe forests in Central Kenya. ***John Ngatia***
1545		**Discussions**
1600	***HEALTH BREAK***	
1630	**Poster Session**	**Poster Session**
1730	***COCKTAIL***	
2000	***DEPARTURE***	

Day 2: Wednesday, 18th April 2018

SESSION IV: Plenary

	Venue: **Auditorium** *Chairperson:* **Prof. M. Larwanou, AFF** *Rapporteurs:* **Mr. Albert Luvanda & Dr. George Muthike**
0830	**Keynote Paper No. 2:** Challenges of climate change in Kenya with reference to forestry and allied natural resources **Dr. Pacifica F. Achieng Ogola** Director, Directorate of Climate Change, Ministry of Environment and Forestry

SESSION V: Parallel Sessions

	Biodiversity and Environment Management (BEM) *Venue:* **Auditorium** *Chair:* **Dr. Esther Kioko, NMK** *Rapporteurs:* **Dr. Beryn Otieno & Dr. Stephen Omondi**	**Socio-Economics, Policy and Governance (SPG)** *Venue:* **Bamboo Room** *Chair:* **Prof. Mahamane Larwanou, AFF** *Rapporteurs:* **Mr. John Ngugi & Mr. Humphrey Gaya**
0900	Distribution of avifauna diversity in vegetation zones of Mt. Elgon forest ecosystem. ***Leonard Likhotio***	Soil carbon sequestration differentials among key forest plantation species in Kenya: Promising opportunities for sustainable development mechanism. ***Vincent Oeba***
0915	Participatory forestry for rehabilitation of degraded peri-urban mangroves in Kenya. ***Donald Maringa***	Local community's perception of forest ecosystem services in Mau, Cherengany and Mt. Elgon and implications for management. ***Abdalla Kisiwa***
0930	Predicting landscape changes of the Malewa River Basin, Kenya under different development scenarios. ***Musa Cheruiyot***	Indigenous traditional knowledge on landscapes, biodiversity use in Mt. Elgon forest ecosystem and implications for conservation. ***David Langat***
0945	Variation in floral and structural composition under controlled resource use and exclusive resource conservation in Mt. Elgon Forest ecosystem. ***John Otuoma***	Effects of natural resource conflicts on well-being of farmers and pastoralists in Kilosa and Kiteto districts, Tanzania. ***Parit Saruni***
1015	Piloting Mangrove REDD+Project In Kenya. ***J. Kairo***	Local actors' perceptions about the impact of prosopis on ecosystem services and land use: The case of Baringo County Kenya. ***Beatrice Adoyo***
1030	**Discussions**	**Discussions**
1045	***HEALTH BREAK***	

SESSION VI: Plenary Session

	Venue: **Auditorium** *Chair:* **Dr. Paul Konuche, Former Director, KEFRI** *Rapporteurs:* **Mr. Albert Luvanda & Dr. George Muthike**
1115	**Keynote Paper No. 3:** Status and future outlook of forestry development in Kenya **Mr. Gideon Gathaara** Conservation Secretary, Ministry of Environment and Forestry

Session VII: Parallel Sessions

	Forest Productivity and Improvement (FPI) *Venue:* **Auditorium** *Chair:* **Dr. Desterio Nyamongo**, KALRO *Rapporteurs:* **Mr. Peter Angaine & Mr. Girehi Giathi**	**Forest Products Development (FPD)** *Venue:* **Bamboo Room** *Chair:* **Dr. Joseph Githiomi**, KEFRI *Rapporteurs:* **Mr. Oscar Mayunzu & Ms Emily Kitheka**
1145	Growth performance of second generation *Pinus maximinoi* and *P. tecunumanii* progeny trials at Turbo, Kenya. ***Willis Atie***	Improved earth and casamance kilns for enhanced efficiency and environmental conservation. ***Nellie Oduor***
1200	Genotypic and plant growth regulator interaction on propagation of jojoba (*Simmondsia chinensis* L.) cuttings in semi-arid areas of Voi, Kenya. ***Shadrack Inoti***	Optimization of piperine extraction from *Piper nigrum* using different solvents for bedbug management. ***Benson Ongarora***
1215	Seed borne Mycoflora associated with stored seeds of three tree species at the Kenya Forestry Seed Centre. ***Ely Mwanza***	Guava preferences amongst children in western Kenya. ***Lusike Wasilwa***
1230	**Discussions**	**Discussions**
1300	***LUNCH***	

SESSION VIII: Parallel Sessions

	Forest Productivity and Improvement (FPI) *Venue:* Auditorium *Chair:* **Dr. Lusike Wasilwa,** KALRO *Rapporteurs:* **Mr. Linus Mwangi & Mr. Emmanuel Makatiani**	Forest Products Development (FPD) *Venue:* **Bamboo Room** *Chair:* **Jan Vandenabeele,** Better Globe *Rapporteurs:* **Ms Rose Chiteva & Ms Violet Oriwo**
1400	Viability of East African Sandalwood seed stored at various temperatures for two years. ***Bernard Kamondo***	Defects in plantation soft wood in Kenya: Causes, extent and distribution. ***George Muthike***
1415	Tracking the bronze bug invasion in Kenya's Eucalyptus planted forests: A nation-wide survey. ***Eston Mutitu***	Piloting biomass energy audit for energy conservation in Homa-Bay County, Kenya. ***Emily Kitheka***
1430	Diversity and activity density of insects on avocado flowers in Kandara, Murang'a County. ***Joseph Mulwa***	Piloting commercial production of charcoal briquettes from sugarcane bagasse in Homa-Bay County. ***Churchill Ogutu***
1445	**Discussions**	Priority non-wood forest products in Cherangany Hills Ecosystem. ***Collins Obonyo***
1500		**Discussions**
1515	Effects of combining organic materials with urea on *Strigo* infestation and maize grain yields in western Kenya. ***Robert Nyambati***	Review of the wood industry in Kenya; technology development, challenges and opportunities. ***George Muthike***
1530	Influence of agricultural lime application with inorganic fertilizers on soil pH and maize yields in western Kenya. ***David Mbakaya***	Synthesis of the development in gums and resins sub-sector in Kenya. ***Meshack Muga***
1545	Meeting the phytosanitary requirements in tree germplasm exchange in East Africa: Awareness on importance, challenges and opportunities of tree seed health among stakeholders. ***Jane Njuguna***	Status of the Bamboo development in Kenya. ***Nellie Oduor***
1600	Discussions	Discussions
1630	Poster Session	Poster Session
1700	*HEALTH BREAK*	
1730	*DEPARTURE*	

Day 3: Thursday, 19th April 2018

SESSION IX: Parallel Sessions

	Forest Productivity and Improvement (FPI) *Venue:* **Auditorium** *Chair:* **Dr. Paul Konuche** -Former Director, KEFRI *Rapporteurs:* **Mr. Joseph Machua & Ms Mary Gathaara**	Knowledge Management & Partnerships *Venue:* **Damboo Room** *Chair:* **Dr. Rosebella Namango,** British Council *Rapporteurs:* **Ms Josephine Musyoki & Mr. James Maua**
0830	Early growth performance and survival of pine hybrids in Turbo and Muguga, Kenya. ***Stephen Omondi***	Evaluation of extension methods in forestry development suitable for increased information dissemination of forestry technologies and innovations in Kilifi and Kwale counties, Kenya. ***Kevin Muema***
0845	Growth Performance of *Pinus kesiya* Royle ex. Gordon provenances in poor soils of Turbo and Nzoia, Kenya. ***Lydia Wamalwa***	Application and impact of knowledge and skills acquired from a participatory natural resources management training in Kenya. ***Josephine Wanjiku***
0900	The potential of *Casuarina equisetifolia* and *Melia volkensii* systems in improving soil fertility in Kwale and Kilifi counties, Kenya. ***Riziki Mwadalu***	The potential of Public Private Partnership (PPP) in forest sector development in Eastern Africa. ***Joshua Cheboiwo***
0915	Compartmentalized allometric equation for estimating volume and biomass of *Eucalyptus grandis* in agroforestry systems in Kenya. ***Nancy Bor***	Public Private Partnerships in forestry sector development in Kenya: Synthesis of status and potentials. ***Joshua Cheboiwo***
0930	**Discussions**	**Discussions**
1000	**Poster Session**	**Poster Session**
1045	***HEALTH BREAK***	

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SESSION X: Invited Papers Plenary

	Venue: **Auditorium** *Chair:* **Dr. Jackson Mulatya**, KEFRI *Rapporteurs:* **Mr. Albert Luvanda & Dr. George Muthike**
1115	**Keynote Paper. No. 4:** The mandate, achievements and challenges of National Research Fund in resource mobilization. **Dr. Jeminah Onsare** Ag. Chief Executive Officer, National Research Fund
1145	Planning, strategies and emerging trends on resource mobilization: NETFUND experiences ***Ms Mary Kiai***, Resource Mobilization Manager NETFUND
1200	Kenya Forest Service experience on long term engagements with development partners: Case of Finnish Government ***Ms Zipporah Chebett***, Head Project Development, Resource Mobilization and Research Liaison, KFS
1215	Enhancing partnerships and resource mobilization in forestry research and development, ***Ms Betty Prissy***, Head Partnership and Resource Mobilization, KEFRI
1230	**Discussions**

SESSION XI: Closing Plenary

	Venue: **Auditorium** *Chair:* **Dr. Ebby Chagala-Odera**, KEFRI *Rapporteurs:* **Mr. Albert Luvanda & Dr. George Muthike**	
1300	Conference highlights	Chief Rapporteur **Dr. Gilbert Obwoyere**
	Official closing Programme	**Chief Guest** **Mr. Charles Sunkuli (CBS)** Principal Secretary Ministry of Environment and Forestry
1400	*LUNCH*	
1500	*DEPARTURE*	

LIST OF POSTERS

POSTERS: FOREST PRODUCTIVITY AND IMPROVEMENT (FPI)

Application of Bio-Char from Sugar Baggase as Organic Soil Amendment Material in Agricultural Production in Homa Bay County, Kenya ***Atie W.***

Effect of Moisture Content and Temperature on Viability and Longevity of *Cordia sinensis* Lam. Seeds ***Ndung'u S.M.***

Applying Stage-Based Matrix Model of on Invasive *Cestrum aurantiacum* Species Population in Mount Elgon Ecosystem ***Ojung'a S.O.***

Effects of Integrated Use of Plant Residues and Urea on Maize Yield Components under *Striga* Infestation in Western Kenya ***Nyambati R.O.***

The Incidence, Severity and Characterization of Botryosphaeriaceae Fungi on *Melia volkensii* Guerke and *Azadirachta indica* L. Trees in Selected Kenyan Arid and Semi-Arid Lands ***Muthama A.M.***

Preliminary Results on Optimal Spacing and Pruning Regimes of *Melia volkensii* in the Dry Areas of Kenya ***Kigwa B.K.***

POSTERS: FOREST BIODIVERSITY AND ENVIRONMENT MANAGEMENT (BEM)

Distribution of Herpetofauna Across Vegetation Zones of Mt Elgon Forest Ecosystem ***Wasonga D.V.***

Effects of Climate Variability on Wild Edible Plant Products Used as a Coping Strategy by Pastoralists of Northern Kenya ***Kagunyu A.***

Land Cover Changes and its Effects on Streamflows in the Malewa River Basin, Kenya ***Kipchumba C.M.***

Status and Rehabilitation Intervention Potential in Dadaab Sub-County, Kenya ***Giathi G.***

Rangeland Rehabilitation Using Micro-Catchments and Native Species in Turkana County, Kenya ***Owino J.***

Towards Rehabilitation of Degraded Woodlands in Charcoal Production Semi-Arid Areas of Embu County, Kenya ***Kigomo J.N.***

Incorporating Blue Carbon Ecosystems in the Kenya's Nationally Determined Contributions to Paris Agreement ***Mwangi N.***

POSTERS: SOCIO-ECONOMICS, POLICY AND GOVERNANCE (SPG)

Experiences of Plantation Establishment and Livelihood Improvement Scheme in Central, Eastern and Mau Forest Conservancies ***Kagombe J.***

Trees on Farm Domestication Level, Opportunities and Challenges: A Case Study of *Prunus africana* in Western Kenya ***Gachie P.K.***

Towards a Sustainable Management of Invasive Alien Trees and Shrubs in Eastern Africa: the 'WoodyWeed' Project ***Schaffner U.***

POSTERS: FOREST PRODUCTS DEVELOPMENT (FPD)

Characterising the Nutritional Composition of *Sclerocarya birrea* (Marula) Fruits in Kenya ***Wairagu N.W.***

POSTERS: INFORMATION AND KNOWLEDGE MANAGEMENT

Tracking the Adoption of Agroforestry Technologies in Kitui and Makueni Counties, Kenya ***Mwalewa S.U.***

Annex II: LIST OF PARTICIPANTS

	Name		Institution
1.	Ng'ethe	Robinson	Chairman, KEFRI Board
2.	Kihara	Kevin	Board Member
3.	Odera	Adhaya Jeptah	Gem Siaya
4.	Agaba	Hilary	NFORRI - Uganda
5.	Konuche	Paul	Kapcheno
6.	Obwoyere	Gilbert O.	Egerton University
7.	Gathaara	Gideon	ME&F
8.	Castermans	Alain	EU
9.	Gacheru	Paul	Nature Kenya
10.	Gussa	Igunzio	ICRAF
11.	Larwanou	Mahamane	African Forest Forum
12.	Kioko	Esther	National Museums of Kenya
13.	Ogola	Pacifica Achieng E.	MEF - CCD
14.	Hitimana	Joseph	University of Kabianga
15.	Ruto	Grace	Via Agroforestry
16.	Kinyanjui	Mwangi	Karatina University
17.	Makokha	Stella	KALRO
18.	Nyamongo	Desterio	KALRO Muguga
19.	Mwangi	Esther	CIFOR, C/O World Agroforestry Centre
20.	Musila	Winne	KWTA
21.	Vandenabeele	Jan	Better Globe
22.	Esilaba	Athony O.	KALRO
23.	Roselida	Owuor	National Research Fund (NRF)
24.	Kenichi	Takano	Forest Policy (CADEP-SFM)
25.	Yuki	Honjo	CADEP - SFM
26.	Namongo	Rosebella	Consultant (KM)
27.	Mwaura	Grace	Consultant (KM)
28.	Mbiru	Sheila	ME&F
29.	Wanjiku	Caroline	FSK, Kiambu
30.	Gikunga	Mary	National Museums of Kenya
31.	Ngugi	John	JICA
32.	Mware	Mugo	Karatina University
33.	Rakwar	John	Mandela Community Dev. Program Makueni
34.	Yaichama	Iganji	KFS
35.	Ann	Juma	KMFRI
36.	Mwihaki	Lilian	KMFRI
37.	Mwasia	Caroline	ME&F
38.	Kinyanjui	Munya	ME&F
39.	Nyamai	Faith	Daily Nation
40.	Munyi	Esther	CIFOR
41.	Muga	Peter	Print Media
42.	Jacinta	KimitI	SEKU

	Name		Institution
43.	Doris	Mutta	African Forest Forum
44.	Abungu	Eric. O.	KFS
45.	Adongo	Alice	KEFRI - LVERP
46.	Adoyo	Beatrice Otieno	CETRAD
47.	Amwatta	Jared	KEFRI - RVERP
48.	Angaine	Peter	KEFRI - CHERP
49.	Atie	Willies	KEFRI - LVERRP
50.	Bala	Pauline	KEFRI - TURBO
51.	Bor	Nancy	KEFRI - HQS
52.	Chebett	Zipporah	KFS
53.	Cheboiwo	Joshua K.	KEFRI - HQS
54.	Chemuku	Wekesa	KEFRI - CERRP
55.	Cheruiyot	Leonida	KEFRI - CHERP
56.	Cheruiyot	Musa	Kenyatta University
57.	Chiteva	Rose	KEFRI - KARURA
58.	Choge	Simon	KEFRI - MARIGAT
59.	Gachie	Peter	KEFRI - LVERRP
60.	Gatama	Stella	KEFRI - CHERP
61.	Gathara	Mary	KEFRI - CHERP
62.	Gathogo	Miriam	KEFRI - CHERP
63.	Gathura	Michael	KEFRI - HQS
64.	Gaya	Humphrey	KEFRI - HQS
65.	Giathi	Gitehi	KEFRI - CERRP
66.	Gichora	Mercy	KEFRI - HQS
67.	Githiomi	Joseph	KEFRI - KARURA
68.	Gitonga	Stephen	KEFRI - HQS
69.	Gituri	James	KEFRI - HQS
70.	Hassn	Elyas	KEFRI - HQS
71.	Imbosa	Swapprinah	KEFRI - HQS
72.	Ingutia	Celestine	KEFRI - HQS
73.	Inoti	Shadrack	Egerton University
74.	James	Kairo	KMFRI
75.	Jaoko	Victor	KEFRI - HQS
76.	Kagunyu	Anastasia	KALRO
77.	Kachenja	Peninah	KEFRI - HQS
78.	Kadenge	Asenath	KEFRI - HQS
79.	Kagombe	Joram	KEFRI - CHERP
80.	Kaigongi	Margaret	KEFRI - CHERP
81.	Kamondo	Bernard	KEFRI - CHERP
82.	Karani	Susan	KEFRI - HQS
83.	Karanja	Mariam	KEFRI - HQS
84.	Kariuki	Jason	KEFRI - CHERP
85.	Kariuki	Joan	CADEP - SFM
86.	Kemboi	Jackline	KEFRI - CHERP
87.	Khalwale	Thalma	KEFRI - RVERP
88.	Kiai	Mary	NETFUND

	Name		Institution
89.	Kiama	Stephen	KEFRI - HQS
90.	Kigwa	Bernard	KEFRI - CERRP
91.	Kimen	William C.	KEFRI - HQS
92.	Kiprop	Jonah K.	KEFRI - CHERP
93.	Kisiwa	Abdalla	KEFRI - RVERP
94.	Kitheka	Emily	KEFRI - KARURA
95.	Koech	Charles K.	KEFRI - LVERP
96.	Komu	Henry	KEFRI - HQS
97.	Kyalo	Joshua	KEFRI - HQS
98.	Langat	David	KEFRI - LVERRP
99.	Lelon	Joseph	KEFRI - CHERP
100.	Likhotio	Leonard M.	Nature Kenya
101.	Lusweti	Agnes	NMK - HQ
102.	Luvanda	Albert	KEFRI - DERP
103.	Machua	Joseph	KEFRI - CHERP
104.	Maina	Samuel	KEFRI - HQS
105.	Makatiani	Emmanuel	KEFRI - CHERP
106.	Mandila	Brexidis	University of Kabianga
107.	Manyeki	Esther	KEFRI - HQS
108.	Manyunzu	Oscar	KEFRI - KARURA
109.	Maringa	David	KMFRI
110.	Maripet	Godfrey	KEFRI - HQS
111.	Maua	James	KEFRI - CHERP
112.	Mb ae	Muchiri	KEFRI - HQS
113.	Mbakaya	David	KARLO
114.	Mbinga	Joram	KEFRI - RVERP
115.	Mbuvi	Tito Musingo	KEFRI - CERRP
116.	Mengich	Edward	KEFRI - RVERP
117.	Michael	Okeyo	KEFRI - DERP
118.	Miingi	Mary	KEFRI - HQS
119.	Mogaka	Sarah	KEFRI - HQS
120.	Mokaya	Risper	KEFRI - HQS
121.	Muchiri	David K.	KEFRI - DERP
122.	Muema	Kevin	KEFRI - CERRP
123.	Muga	Meshack	KEFRI - KARURA
124.	Mugendi	Lydia	KEFRI - CERRP
125.	Mukiha	Esther Nge'ndo	KEFRI - HQS
126.	Mukolwe	Michael	KEFRI - CHERP
127.	Mulatya	Jackson	KEFRI - HQS
128.	Mulwa	Joseph	KALRO - Kabete
129.	Munga	Kinyanjui	KEFRI - HQS
130.	Musau	Joshua	Karatina University
131.	Musyoki	Josephine	KEFRI - Kibwezi
132.	Muriithi	Stephen Ndung'u	KEFRI - CHERP
133.	Muthama	Angela	KEFRI - CHERP
134.	Muthike	George	KEFRI - Karura

	Name		Institution
135.	Mutitu	Eston	KEFRI - CHERP
136.	Mutunga	Kennedy	KEFRI - HQS
137.	Muturi	Gabriel	KEFRI - HQS
138.	Mwalewa	Sylvia	KEFRI - CERRP
139.	Mwandalu	Riziki	KEFRI - CERRP
140.	Mwangi	Linus	KEFRI - CHERP
141.	Mwanza	Ely	KEFRI - CHERP
142.	Mwaura	James	KEFRI - HQS
143.	Nadir	Stanley	KEFRI - CERRP
144.	Ndalilo	Leila	KEFRI - HQS
145.	Ndufa	James K.	KEFRI - DERP
146.	Nereoh	Leila	KEFRI - HQS
147.	Nganga	Mwangi	KEFRI - HQS
148.	Ngatia	John	Wangari Maathai Institute, UoN
149.	Ngugi	John Kigomo	KEFRI - CHERP
150.	Njehu	Jane	KEFRI - CHERP
151.	Njenga	Esther	KEFRI - HQS
152.	Njoki	Betty Prissy	KEFRI - HQS
153.	Njuguna	Jane	KEFRI - HQS
154.	Njuguna	Jonathan	KEFRI - CHERP
155.	Nyambati	Robert	KEFRI - RVERP
156.	Nyarindo	Hellen K.	KEFRI - HQS
157.	Oballa	Phanuel	KEFRI - HQS
158.	Obonyo	Collins	KEFRI - Karura
159.	Ochieng	Dorothy	KEFRI - HQS
160.	Ochung	Francis	KEFRI - HQS
161.	Odee	David	KEFRI - HQS
162.	Odera	Ebby Chagala	KEFRI - HQS
163.	Oduor	Nellie	KEFRI - Karura
164.	Oeba	Vincent O.	African Forest Forum
165.	Ogutu	Peter Churchill	KEFRI - Karura
166.	Ojung'a	Samson Okoth	KEFRI - LVERP
167.	Okeyo	Michael	KEFRI - DERP
168.	Okumu	Joyce	KEFRI - RVERP
169.	Omondi	Brian	KEFRI - HQS
170.	Omondi	William	KEFRI - CHERP
171.	Omondi	Stephen	KEFRI - CHERP
172.	Onganda	Paul	CADEP - SFM
173.	Ongorora	Benson	Dekut
174.	Ongugo	Paul	KEFRI - HQS
175.	Opiyo	John	MMUST
176.	Oriwo	Violet	KEFRI - HQS
177.	Oroni	Evelyn	KEFRI - HQS
178.	Osano	Phesto	KEFRI - HQS
179.	Oscar	Manyunzu	KEFRI - Karura
180.	Osoro	Rose B.	KEFRI - HQS

Name			Institution
181.	Othim	Roxventa	KEFRI - CHERP
182.	Otieno	Beryn	KEFRI - CHERP
183.	Otwoma	John	KEFRI - LVERRP
184.	Owino	Jesse	KEFRI - RVERP
185.	Owuor	Benard	KEFRI - MIGORI
186.	Pole	Finyange	KARLO - Matuga
187.	Priscilla	Kimani N.	KEFRI - CHERP
188.	Riziki	Mwandalu	KEFRI - CERRP
189.	Rob	Galgalo	KEFRI - HQS
190.	Saruni	Parit	SUA - Morogoro Tanzania
191.	Sayah	Abuid A.	KEFRI - HQS
192.	Schaffner	URS	CABI
193.	Sheikh	Mohamed A.	KEFRI - DERP
194.	Sigu	Gordon	ME&F
195.	Titus	Masinde	KEFRI - LVERP
196.	Towett	Florence	KEFRI - CHERP
197.	Tuwei	Paul	KEFRI - HQS
198.	Wairagu	Norman Wachira	KEFRI - Karura
199.	Wairungu	Simon	KEFRI - CHERP
200.	Wakesho	Sarah	KEFRI - HQS
201.	Wamalwa	Lydia	University of Nairobi
202.	Wanjiku	Ivy	KEFRI - HQS
203.	Wanjiku	Josephine	KEFRI - HQS
204.	Wasilwa	Lusike	KARLO
205.	Wasonga	Dominic	NMK
206.	Wekesa	Anne	KEFRI - HQS
207.	Wekesa	Linus	KEFRI - CERRP
208.	Welimo	Martin	KEFRI - TURBO
209.	Muwa nu	Cecilia	KEFRI - HQS

Annex III: ALIGNING OF CONFERENCE PRESENTATIONS TO THE GOVERNMENT OF KENYA 2018 TO 2022 BIG FOUR AGENDA

Theme 1. Forest Productivity and Improvement

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
1.	Growth Performance of Second Generation *Pinus maximinoi*and *P. tecunumanii* Progeny Trials at Turbo, Kenya	Identification of pine species suitable for growing in Kenya	Manufacturing Affordable housing	Broaden species diversity for plantation establishment in the Kenya highlands, for pulpwood, timber, fuelwood and resin production
2.	Genotypic and Plant Growth Regulator Interaction on Propagation of Jojoba (*Simmondsia chinensis* L.) Cuttings in Semi-arid Areas of Voi, Kenya	Promotion of Jojoba propagation by hormones	Manufacturing	Development of Jojoba plantations for use in industries to make cosmetics, lubricants and pharmaceuticals
3.	Seed Borne Mycoflora Associated with Stored Seeds of Three Tree Species at the Kenya Forestry Seed Centre	Information on seed borne fungi	Affordable housing Healthcare Manufacturing	Knowledge on management of key fungi for provision of viable planting materials for afforestation programs to have raw materials for construction, energy sector and pharmaceutical industry
4.	Viability of East African Sandalwood Seed Stored at Various Temperatures for Two Years	Post-harvest handling of sandalwood seeds	Manufacturing	Sustainable provision of raw materials for cosmetic and pharmaceutical industry

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
5.	Tracking the Bronze Bug Invasion in Kenya's Eucalyptus Planted Forests: A Nation-Wide Survey	Integrated pest management	Affordable housing Manufacturing	Knowledge on spread and management of key Eucalyptus species pest for sustainable provision of raw materials for construction industry and electricity transmission poles
6.	Diversity and Activity Density of Insects on Avocado Flowers in Kandara, Murang'a County	Improving avocado productivity through enhanced pollination	Food security Manufacturing	Increase productivity of avocado for domestic use and export Provision of raw material for cosmetic industry
7.	Effect of Combining Organic Materials with Urea on Striga Infestation and Maize Grain Yields in Western Kenya	Improving soil fertility to control Striga weed	Food security	Improve soil fertility through application of Calliandra biomass as an organic fertilizer in order to reduce Striga infestation and consequently enhance maize crop production
8.	Influence of Agricultural Lime Application with Inorganic Fertilizers on Soil pH and Maize Yields in Western Kenya	Liming to reduce soil acidity	Food security	Liming reduces soil acidity, hence enhancing fertilizer use efficiency and consequently increasing agricultural productivity
9.	Meeting the Phytosanitary Requirements in Tree Germplasm Exchange in East Africa: Awareness on Importance, Challenges and Opportunities of Tree Seed Health among Stakeholders	Information to promote clean germplasm exchange	Affordable housing	Ensuring provision of high quality tree seeds for plantation establishment and on farm planting
10.	Early Growth Performance and Survival of Selected Pine Hybrids in Turbo and Muguga, Kenya	Identification of pine hybrids suitable for growing in Kenya	Manufacturing Affordable housing	Diversification of plantation tree species useful for pulp and paper; and construction industry

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
11.	Growth Performance of *Pinus kesiya* Royle ex Gordon Provenances in Poor Soils of Turbo and Nzoia, Kenya	Identification of pine provenances suitable for growing in Kenya	Manufacturing Affordable housing	Growing of *Pinus kesiya* will diversify plantation species for pulpwood, timber and resin production
12.	The Potential of *Casuarina equisetifolia* L. and *Melia volkensii* Gürke in Improving Soil Fertility in Kwale and Kilifi Counties, Kenya	Use of trees to improve soil fertility	Food security Affordable housing	Improvement of soil fertility consequently increasing yields of both crops and raw materials for construction
13.	Compartmentalized Allometric Equation for Estimating Volume and Biomass of *Eucalyptus grandis* in Agroforestry Systems in Kenya	Information for assessment of Eucalyptus productivity	Manufacturing Affordable housing	Information to determine wood biomass for use in construction industry and woodfuel for processing of agricultural-based products, and brick curing
14.	Application of Biochar from Sugar Baggase as Organic Soil Amendment Material in Agricultural Production in Homa Bay County, Kenya	Biochar from sugar bagasse for soil improvement	Food security	Retention of soil nutrients and moisture, and accumulation of soil organic matter which improves crop productivity
15.	Effect of Moisture Content and Temperature on Viability on Longevity of *Cordia sinensis* Lam. Seeds	Seed storage technology	Affordable housing	Improve quality and quantity of planting of seeds for plantation establishment
16.	Applying Stage-based Matrix to Model the Invasive *Cestrum aurantiacumm* Lindl. Population in Mount Elgon Ecosystem	Use of Mathematical models to study the trends of invasive species	Food security Affordable housing	Invasive species affect productivity of both farmlands and forests hence understanding the population structure contributes to developing strategies for its control
17.	Effects of Integrated Use of Plant Residues and Urea on Maize Yield Components Under Striga Infestation in Western Kenya	Use of plant residues as alternative sources of fertilizers	Food security	Improved food security by increasing crop yields under agroforestry systems for resource poor farmers

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
18.	The Incidence, Severity and Characterization of Botryosphaeriaceae fungi on *Melia volkensii* Guerke and *Azadirachta indica* A. Juss. Trees in Kenya's Arid and Semi-arid Lands	Identification of fungi associated with some trees species in the drylands	Affordable housing Manufacturing	Provides information on management and control of fungi on tree species to ensure healthy trees in plantations and on farms
19.	Preliminary Results on Optimal Spacing and Pruning Regimes of *Melia volkensii* in the Dry Areas of Kenya	Establishment and management of Melia for optimal tree growth	Affordable housing	Sustainable and high quality timber production on farms and in plantations for timber supply in drylands

Theme 2. Biodiversity and Environment Management

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
1.	Benchmarking edaphic properties of Arabuko Sokoke forest for long-term biodiversity monitoring	Information	Universal health care Food security	Sustainable management of Arabuko Sokoke Forest which is key to livelihoods of forest-adjacent communities
2.	Water quality status in Mt. Elgon and Cherangany forested ecosystems	Status of pollution level of water in Mt Elgon and Cherangany ecosystems	Universal health care	Ensuring use of clean water will reduce diseases incidences
3.	Population Structure of *Prunus africana* (HOOK.f.) Kalkm. and Olea europaea L. in South Nandi Afromontane Forest, Kenya	Methodology for monitoring status of tree resources in natural forests	Universal health care	Sustainable supply of raw materials for pharmaceutical industry
4.	Evidence of Genetic Diversity and Taxonomic Differentiation Among *Acacia senegal* Populations and Varieties in Kenya	Selection tool for high gum content yielding varieties for *Acacia senegal*	Manufacturing	Sustainable provision of raw materials to food, beverage, and emulsion manufacturing industries
5.	Anthropogenic Influences on Species Composition, Richness and Diversity in Museve and Mutuluni Dryland Forest Fragments, Kitui; Kenya.	Methodology for monitoring status of tree resources in dryland forests	Food security	Conservation of biodiversity in drylands important in ensuring healthy bee colonies which are important in pollinating agricultural food crops

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
6.	Interactions Between Native Tree Species and Environmental Variables Along Forest Edge-Interior Gradient in Fragmented Forest Patches of Taita Hills, Kenya	Information	Food security Universal health care	Information gathered would guide policy makers in catchment rehabilitation and restoration
7.	Effect of Water Conservation Method on the Yield of Coconuts	Appropriate technology for water and soil fertility conservation	Food security Manufacturing	Enhancing productivity of Coconut which has the potential to substitute 30% of the edible oil imports into the country. Sustainable supply / provision of raw materials for industry (ensure continued nut production throughout the year): Increased availability of raw materials for edible and non-edible oils, fibre of commercial value, coconut shell for fuel and industrial uses, thatching materials (makuti), palm wine (toddy), brooms, and timber for construction and furniture making
8.	Interactions between Native Tree Species and Environmental Variables Along Forest Edge-interior Gradient in Fragmented Forest Patches of Taita Hills, Kenya	Approach for selecting native tree species for rehabilitation programs to restore degraded sites within forest fragments	N/A	N/A

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
9.	Linking different levels of forest degradation to suitable forest restoration techniques in selected forests in western Kenya	Technology	Universal health care Food security	Also indirectly contributes to Manufacturing and Affordable housing. Supply
10.	The Fate of Taita Hills' Forest Fragments: Evaluation of forest cover change between 1973 and 2016 using Landsat Imagery	Information on impacts of different forest tenure on changes in forest cover in Taita Hills	N/A	N/A
11.	Land Cover Changes and its Effects on Streamflows in the Malewa River Basin, Kenya	Information on impacts of land cover change on stream flows	N/A	N/A
12.	Destruction of watershed forests beyond trees: Effects of anthropogenic disturbance on forest herpetofauna of Cherangani Hills Forest	Information on herptofauna diversity in Chrangani	N/A	N/A
13.	Incorporating Blue Carbon Ecosystems in the Kenya's Nationally Determined Contributions to Paris Agreement	Protection and restoration of mangrove ecosystems through the provision of and payment for quantifiable	Food security	Protection of mangrooves which provided breeding grounds for fish populations at the coast

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
		ecosystem services		
14.	Distribution of Avifauna Diversity in Vegetation Zones of Mt. Elgon Forest Ecosystem	Information on how vegetation impacts on bird species diversity	N/A	N/A
15.	Participatory Forestry for Rehabilitation of Degraded Peri-Urban Mangroves in Kenya	Rehabilitation of degraded mangroves	Food security	Protection of mangrooves which provide breeding grounds for fish populations at the coast
16.	Predicting landscape changes of the Malewa River Basin, Kenya under different development scenarios	Information	Food security	Provides information to assist policy makers in decision making.
17.	Variation in Floral and Structural Composition of Vegetation under Controlled Resource Use and Exclusive Resource Conservation in Mt. Elgon Forest Ecosystem	Information on impacts of different forest tenure and management options on the floral characteristics in Mt Elgon Forest Ecosystem	N/A	N/A
18.	Distribution of Herpetofauna across vegetation zones of Mt Elgon Forest	Information	N/A	N/A

No.	**Title of Paper**	**Technology / Information**	**Which of Big Four Agenda it Contributes to**	**How it Contributes**
	Ecosystem			
19.	Effects of Climate Variability on Wild Edible Plant Products Used as a Coping Strategy by Pastoralists of Northern Kenya	Information	Food security Universal health care	Provides information to assist policy makers in decision making towards resilience to climate variability among pastoralists.
20.	Land Cover Changes and its Effects on Streamflows in the Malewa River Basin, Kenya	Information	Food security	Provides information to assist policy makers in decision making towards restoration of Malewa River basin
21.	Degradation status and rehabilitation intervention potential in Dadaab Sub-county, Kenya	Information and rehabilitation technology	Affordable housing Universal health care	The information can guide decisions at policy level with respect to environmental conservation
22.	Rangeland rehabilitation using micro-catchments and native species in Turkana County, Kenya	Rehabilitation technology	Affordable housing, Food security Universal health care	It contributes to successful rehabilitation of rangelands by improving their conditions, leading to higher productivity
23.	Towards Rehabilitation of Degraded Woodlands in Charcoal Production Semi-Arid Areas of Embu County, Kenya	Rehabilitation technology	Affordable housing Food security	With anticipated increase in wood production, there would be higher supply of wood for construction and more for sale to obtain cash to exchange with food. The study has revealed tree species-site matching is crucial during woodland landscape restoration planning and implementation

Theme 3. Socio-economics, Policy and Governance

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
1.	On-Farm Tree Growing Opportunities and Constraints in Murang'a County, Kenya	On-farm tree-growing technology	Food security Affordable housing Manufacturing	Trees grown on-farm intercrop with food crops that contribute to increased crop yield through agroforestry. Fodder trees are used for agroforestry which increase production in dairy animals. The products from these trees are used for construction and in furniture industry
2.	Adoption of *Calliandra Calothyrsus* for Improved Dairy Production in Embu County, Kenya	Fodder production technology from tree shrubs	Food security	Fodder from Calliandra is fed to dairy animals as a protein supplement thus reducing cost of purchasing commercial concentrates and increasing milk production. Adoption rate of 86% leading to higher milk production and improved quality of manure.
3..	Gender Related Aspects in Adoption of Biomass Energy Conservation Technologies in Four Selected Areas of Kitui County	Gender mainstreaming in biomass production	Food security	Enhanced gender mainstreaming will lead to improved biomass that will in return lead to food security
4.	Status and Growth Determinants of Non-Timber Forest Products Firms in Kenya	Evaluation of capacity of NTFP	Manufacturing Food security	Increased production of NTFP will support manufacturing as some NTFPs are used in food processing and as food. Capacity building will lead to increased food productivity

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
5.	Management of *Prosopis juliflora* Invasion in Baringo County through Utilization	Utilization of Prosopsis as strategy to reduce its invasiveness and create income for households	Food security Manufacturing Affordable housing	Reduction of invasiveness will lead to higher food production as well use for honey production, support manufacturing through use as poles and charcoal, while pods are used in production of animal feeds
6.	Cost-Benefit Analysis of Agroforestry Technologies in Semi-Arid Regions of West-Pokot County, Kenya	Agroforestry technologies	Food security Affordable housing	Fodder banks provide feed for domestic animals for income and food while trees planted including Cypress and Eucalyptus are used for construction of houses and manufacturing
7.	Markets and Price Trends for Key Tradable Forest Products in Kenya from 1999 - 2014	Prices of forest products	Manufacturing Affordable housing	Information on prices of forest products contribute to manufacturing by adding value to forest products through e.g. timber sawing and charcoal production. The availability of the products e.g. timber and construction poles contribute to affordable housing
8.	Financial Assessment of Woodlots on Smallholdings in Coast of Kenya	Optimization of high value trees in farming production systems	Food security Affordable housing	Revenue from tree farming will lead to improvement of household incomes that will contribute to food security and be used in production of wood products in the manufacturing sector
9.	Value of Pollination Services in Farmlands Adjacent to Mau, Cherngani, and Mt. Elgon	Technology on using economic valuation to	Food security	Pollination contribution to food crops in Mau, Cherangani and Mt. Elgon was

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
	Forest	determine value of pollination		valued at 931 million in 2015 thus highly contributing to food security in those regions
10.	The Value of Forest Ecosystem Services of Mau Complex, Cherangany and Mt. Elgon, Kenya	Value of forest ecosystems services	Food security Manufacturing Affordable housing Universal health	The Value of Forest Ecosystem Services of Mau Complex, Cherangany and Mt. Elgon, Kenya will lead to allocation of more resources to manage the water towers. Well managed water towers will provide more water(for agriculture & generation of electricity), provision of medicinal plants, and building materials for houses.
11.	Evaluating Willingness to Pay for Watershed Protection in Ndaka-ini Dam, Murang'a County, Kenya	Guidelines on payment for ecosystem services	Food security Manufacturing Universal health	Well conserved catchment areas and improved farm practices will lead to increased food production at household level, improved water quality for consumption thus reducing water borne diseases and enhance production due to reliable water supply
12.	From the Wild to Markets and Farmlands: Plant species in Biotrade	Biotrade technology	Food security	Increasing food sources from wild fruits in the markets through domestication, conservation and sustainable utilization
13.	Participatory Forest Management: A Case of Equity in the Forest Plantation Establishment and Livelihood Improvement Scheme in	Forest Plantation Establishment and Livelihood	Food security	Forest Plantation Establishment and Livelihood Improvement Scheme contribute to food security by farmers

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
	Gathiuru and Hombe Forests in Central Kenya	Improvement Scheme	Manufacturing Affordable housing	growing food crops during the early tree establishment phase, manufacturing through processing mainly of timber harvested and affordable housing by provision of building materials including timber and poles and posts
14.	Soil Carbon Sequestration Differentials among Key Forest Plantations Species in Kenya: Promising Opportunities for Sustainable Development Mechanism	Soil carbon sequestration and trading	Health	Creation of carbon sinks as growing trees and promoting carbon trading will lead to reduction in carbon emissions that will in return improve health for humanity
15.	Local community's perception of forest ecosystem services in Mau, Cherengany and Mt. Elgon and implications for management	Information technology	Health	Appreciation of community perception to ecosystem services leading to improved health of the ecosystem which directly affect human health
16.	Indigenous traditional knowledge on landscapes, biodiversity use in Mt. Elgon forest ecosystem and implications for conservation	Information technology Traditional indigenous knowledge in biodiversity conservation	Health	Use of traditional knowledge to enhance health of ecosystem and use of traditional knowledge to secure human health since some trees have medicinal value.
17.	Effects of natural resorce conflicts on well-being of farmers and pastoralists in Kilosa and Kiteto Districts, Tanzania	Well-being of farmers and pastoralists	Health	Management of conflicts on natural resource use contributes to well-bieng of farmers and pastoralists
18.	Local Actors' Perceptions about Prosopis'	Impacts assessment	Food security	Reduction of invasiveness will lead to higher food production and support

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
	Impacts on Ecosystem Services and Land		Affordable housing	manufacturing through use of Prosopis as a source of poles, charcoal, and pods used in production of animal feeds
19.	Evaluation/experiences of Plantation Establishment and Livelihood Improvement Scheme as Method for Raising Forest Plantations in Kenya	Forest establishment technology	Food security Manufacturing Affordable housing	Forest plantation established are source of wood products used in manufacturing timber products that are used in housing and paper production. Crops grown by farmers in PELIS contribute to household food security
20.	Domestication, opportunities and challenges of trees on farms: a case study of Prunus africana in western Kenya	Tree domestication technology	Health	Promotion of domestication of *Prunus africana* will avail raw products for traditional and modern medicine that will contribute to improved health for Kenyans
21.	Towards a Sustainable Management of Invasive Alien Trees and Shrubs in Eastern Africa: The ‘Woody Weeds’ Project	Management of invasive alien trees and shrubs	Affordable housing Manufacturing	Invasive alien trees and shrubs colonize beneficial trees. Management of these trees will lead to increased tree production for construction timber and furniture for industry

Theme 4. Forest Products Development

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
1.	Improved Earth and Casamance kilns for enhanced efficiency and environmental conservation	Technology on improved Earth and Casamance kilns	Manufacturing	The kilns can be manufactured and sold as an enterprise
2.	Optimization of Piperine Extraction from *Piper nigrum* using different Solvents for Bedbug Management	Technology on the management of bed bugs	Universal healthcare	The piperine can act as an insecticide against bed bugs
3.	Guava preferences among children	Information on the availability and preference of guava in western Kenya	Food security	The information will help guide research on varieties of guava to plant for a diversified diet
4.	Defects in Plantation Soft Wood in Kenya: Causes, Extend and Distribution	Estimate of defective wood in Cypress plantations (information)	Affordable housing	Reduces waste of raw materials and logging costs
5.	Piloting Biomass Energy Audit for Energy Conservation in Homa-Bay County, Kenya	Biomass energy audit and energy saving stoves (information)	Manufacturing	Create employment (those employed in stoves making) and increase trade (those selling)
6.	Piloting commercial production of charcoal briquettes from sugarcane bagasse in Homa Bay County	Technology on briquette making efficiency and distribution	Manufacturing	Provides green energy that can be used as industrial fuel

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
7.	Priority Non-Wood Forest Products in Cherang'any Hills Ecosystem	Information	Food security	Quantifying the various fruits and vegetables and their economic value to the community
8.	Review of the Wood Industry in Kenya; Technology Development, Challenges and Opportunities	Information on Opportunities to invest and develop forestry sector in Kenya	Affordable housing	The information discusses expansion of wood industry and wood products base
9.	Synthesis of the Development in Gums and Resins Sub-Sector in Kenya	Information	Manufacturing	Identifies the existing and potential contribution of the gums and resins to the local economy
10.	Status of the Bamboo Development in Kenya	Area and distribution of bamboo in Kenya; suggestions on how bamboo can be sustainably managed (information)	Affordable housing Manufacturing	Use bamboo in construction and develop bamboo industry
11.	Characterizing the Nutritional Composition of *Sclerocarya birrea* (Marula) Fruits in Kenya	Knowledge on the nutritional composition of *Sclerocrrya birrea* fruits in Kenya	Food security	The fruits can supplement in specific nutrients that they can supply

Theme 5. Information, Knowledge Management and Partnership

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
1.	Application and Impact of Knowledge and Skills Acquired from Participatory Natural Resources Management Training in Kenya	Application and adoption of knowledge and skills acquired (information)	Food security	Increased tree planting and environmental conservation activities
2.	Tracking the adoption of Agroforestry technologies in Kitui and Makueni Counties, Kenya	Information on adoption levels of agroforestry	Food security	Provides basis for promotion of agroforestry in ASALs for increased food production and resilience
3.	Evaluation of Extension Methods in Forestry Development Suitable for Increased Information Dissemination of Forestry Technologies and Innovations in Kilifi and Kwale Counties, Kenya	Effective methods for technology disseminations	Food security	Increased tree planting and environmental conservation activities
4.	The Potential of Public Private Partnership (PPP) in Forest Sector Development in Eastern Africa	Information on the partnership that exists between the private and public sectors in the development of forest products in East Africa	Manufacturing	Wood based industries can be developed based on this information

No.	Title of Paper	Technology / Information	Which of Big Four Agenda it Contributes to	How it Contributes
5.	Public Private Partnerships in forestry sector development in Kenya: Synthesis of status and potentials	Information on the opportunities for partnerships to develop forestry sector in Kenya	Manufacturing, Affordable housing Food security	The paper discusses opportunities for an efficient and robust forestry sector where all stakeholders are involved.
6.	Enhancing partnerships and resource mobilization in forestry research and development	Information on best practices in resource mobilization and partnerships	N/A	N/A