COLLEGE OF AGRICULTURE, ANIMAL SCIENCES AND VETERINARY MEDICINE

ASSESSMENT OF IMPACTS OF REMOVING EUCALYPTUS SPECIES ON NATURAL REGENERATION OF NATIVE SPECIES AT GISHWATI-MUKURA NATIONAL PARK

Dissertation submitted for partial fulfillment for the award of MSc Degree in Agroforestry and Soil Management By Fulgence HAGUMUBUZIMA.

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Huye, September 2019

DECLARATION

I, Fulgence HAGUMUBUZIMA, declare that this dissertation titled "assessment of impacts of removing *Eucalyptus* species on natural regeneration of native species at Gishwati-Mukura National Park" is the result of my own work and has not been submitted for any other degree at the University of Rwanda or any other institution.

Declaration on the use of the anti-plagiarism checker.

Printed Name: Fulgence HAGUMUBUZIMA

Signature:

Declaration from the Main Supervisor that he is approving submission of the dissertation for examination.

Prof. NSABIMANA Donat

Signature:

DEDICATION

This dissertation is dedicated to:

All might of God

My beloved family,

My parents

My brothers and sisters,

My supervisors,

ACKNOWLEDGEMENTS

I am grateful to the almighty of God who protected me during all my study.

My deepest thankful to my main supervisor Prof. Donat NSABIMANA and co-supervisor Dr. Athanase MUKURALINDA for their guidance and advices during the whole research dissertation. I cannot forget the authority of Landscape Approach to Forest Restoration and Conservation (LAFREC) project under REMA who financially supported during the research process and the Centre of Excellence in Biodiversity who corrected and gave constructive comments during research writing process.

I remain thankful to all lecturers of UR/ CAVM in Agroforestry and Soil Management program who taught me and guided during the whole course works studies,

I would like also to acknowledge Mr. ZIBERA Etienne and Mr. NDAGIJIMANA Isidole, for their memorable support during my MSc. dissertation writing. I offer my sincere gratitude to KABENGA Edison who guided me during field data collection and identified the local names of plant species.

May God bless you all!

Abstract

The aim of this research was to assess the impacts of removing the *Eucalyptus* species on the natural regeneration of native species at Gishwati-Mukura National Park. The eighteen study sites were selected from the *Eucalyptus* species removed and non-removed areas, with three and five randomized plots in each site of Mukura and Gishwati sides respectively to identify the native and non-native plant species regenerated, the number of E. stumps regenerated, and E. seedlings germinated. A quadrat of 1m^2 was used for the herbs species identification, 25m^2 and 100m^2 for the identification of the woody species (shrubs and trees) having less than 2m and greater or equal to 2cm of diameter at breast height correspondently. A straight line of 100m long from the edge of the buffer zone was drawn in and out the Park to identify the distribution potential of *Alnus* inside and outside of the Park. A quadrat of 1m^{2}used for quantification of the number of *Alnus* seeds and seedlings germinated at 0, 5, 15, 30, 50, 75 and 100m distances. The plants species abundance, diversity indices, evenness and the coppiced stumps abundance were analyzed with the Excel sheet, pivot table and bioproffessional software.

The total of 20 *Eucalyptus* stumps were coppiced among 197 E. stumps counted in the whole study area and 3 E. seedlings were identified. The estimated number of herbs species were highly abundant at E. removed area at 60 herbs species compare to 13 herbs species in non-E. removed areas per 1m^{2}at Mukura side. Gishwati side was 57 herbs species in E. removed area compare to 16 herbs species in non E. removed area per 1m^{2}with high dominance of the *Coelachne africana, Phyllanthus nummulariifolius* herbs in both study sides. The areas were highly dominated by the pioneer woody species such as *Macaranga kilimandscharica, Maesa lanceolata, Dombeya torida, Bothriocline ruwenzoriensi*, *Xymalos monospora,* and low abundance of climax species like *Carapa grandiflora*, *Podocarpus falcatus, Syzygium guinens* in the whole study area. The results shown that the E. species had numerous influence on the native species regeneration by competing with native species, the E. leaves litter and chemical substances inhibiting the regeneration of native species in the nature area.

Key words: Biodiversity; plant species diversity; abundance; Gishwati, Mukura national Park; *Euclyptus*; *Alnus*; regeneration

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List of abbreviations

ANR: Accelerated Natural Regeneration

CAVM: Colle of Agriculture, Animal science and Veterinary Medicine

DBH: Diameter at Breast Height

GPS: Global Position System

H’: Shannon diversity index

J: Evenness index

LAFREC: Landscape Approach to Forest Restoration and Conservation

REMA: Rwanda Environmental Management Authority

UR: University of Rwanda

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CHAPTER 1. INTRODUCTION

The *Eucalyptus* species originated in Australia and was introduced elsewhere for its fast growth, timber and energy production (Tang et al., 2007; Zhao et al., 2007). It is easily established with high growth performance and high production, however the *Eucalyptus* species become invasive to its surround natural plantation (Calvino-cancela et al., 2013). This resulted to the loss of biodiversity in the understory and degrading the soil. Hua-Feng Wang et al. (2011)have shown the reduction of biodiversity in the *Eucalyptus* plantation which was a critical issue for the long term of native ecosystem.

In China, different varieties of *Eucalyptus* were introduced and presented the high proliferation in the country and caused a high decrease of biodiversity due to its chemical substances contained by E. leaves (Chu et al., 2014).

In Florida, different plant species planted, 30% is made of the exotic species (non- native species) which were established from other countries or region and became invasive in the area with the high growth and spreads, this caused the loss of habitant for native species (bird, plant and other wild animal) and the reduction of biodiversity (Demers et. al., 2016). According to Milestones (2010), among the harmed exotic species to the native species includes plant *Eucalyptus* species which inhibit natural processes and the continuance of natural features of native species and there is a need for the management of exotic species for the protection of the park's natural and cultural resources from the impacts of the exotic species.

The study conducted at Sierra Nevada exposed that the most exotic species found in the natural ecosystem were introduced either by human activity, transport, and or environment modification and provide opportunities to be established in natural area. The introduced exotic species were harmful to the native species by extinction of native species and destruction of biological diversity and decrease the population of native species (Dyer, 1996).The humans' activities contributed significantly in spreading the exotic plant species in the ecosystem and become abundant in human- influenced ecosystems(Knops et al., 2014).

The Gishwati Forest Reserve, a hundred years ago, was a secondary mountain rain forest with the largest number of indigenous species in Rwanda and covered approximately 100,000 hectares. In 1970, the area was reduced to a fourth of the total size to 28,000 hectares; due to cattle ranching (39.6%), human settlement and small farms (38.6%) and planted Pine and *Eucalyptus* woodland (12.5%) (Kisioh, 2018).

In 1980, 70% of the total area of the Gishwati natural forest was converted into pasture land and *Eucalyptus* species plantation alongside cattle ranching (Kisioh, 2018). After the 1994 Genocide, refugees resettled in Gishwati-Mukura natural forest which resulted in the clearing of native forest for agriculture and establishment of non-native species including *Eucalyptus spp* and *Acacia meansis* (Kisioh, 2018).

Thereafter the communities surrounding the Gishwati-Mukura landscape continued to enter inside the forest to cut down trees (both native and non-native trees species) for timber, rope, stick, bamboo and medicinal plants collection to satisfy their needs (Kisioh, 2018).

Large areas within the Gishwati-Mukura landscape have been threatened by the established exotic species (*Eucalyptus* sp, *Acacia meansis* and *Acacia melanoxylon*) (Richardson et al, 2006). The exotic species occupied the natural area and have the capacity to be established themselves in natural area and compete the native species, kill and displaced them in the native habitant (Kisioh, 2018).

The exotic seeds dispersal in the natural area contribute to forest dynamics. The success of seeds dispersal is subject to the amount of seeds dispersed, the viability and kind of treatment provided by seed dispersers. (Isabel & Pinto, 2018). According to Bullock & Clarke (2000) invasive species seeds can be dispersed and be invaders if they reached in the appropriate environment. Many seeds have dispersed in the short distance and the few seeds reach longer by human intervention. The dispersal of exotic species varies with the seeds and the host environment. The *Alnus* species is originated from Mexico, was planted along side of Gishwati as the buffer zone to delimit the movement of people entering in the park and reduce the level of the encroachment. The *Alnus* species have small seed which can be dispersed by wind for the long distance and by gravity for short distance. The number of *Alnus* species seeds in one kilogram is more than 2 million pure seeds which can germinate at 50-70% in the good condition (Orwa C et al., 2009). The *Alnus* species have shading effect and degrading nature habitat. The species forms monospecific stands that out-compete native species to the water, nutrients and sunlight (Anderson and Hayley, 2013). The spread of exotic species varies with its invasiveness and community invasibility (Calviño-cancela & Rubido-bará, 2013).

1.1. Problem statement

The degradation of the Gishwati-Mukura landscape is a result of over-exploitation of natural resources through agricultural, livestock and mining activities which have consequently resulted in the loss of biodiversity, including indigenous plant species, wild animals, birds, ecological integrity and ecosystem functions (services and products) as well as the increase of exotic species in the landscape (Kisioh, 2018). The *Eucalyptus* species is one of the established exotic tree species in the park, which have high competition to the native plant species in term of light, soil water and nutrients leading to its high growth in the ecosystem and totally displaced native species from their native habitat through diseases to which they have not developed resistance, outcompete them as well as alteration of ecological functions (Heras et al., 2013) and change the microbial community structure and function in the soil (Kourtev et al., 2015). The impact assessment of removing the *Eucalyptus* species on the nature regeneration has never been studied at Gishwati-Mukura National park. Therefore, this research is very crucial, because the native species regenerated in the area will provide the information on how the ecological functionality and environmental balance will be after the removal of *Eucalyptus* species. The aim of this research was to assess the effect of removing *Eucalyptus* species on natural regeneration of native species in the Gishwati-Mukura National Park. The specific objectives were: (i) to evaluate the number of *Eucalyptus* stumps coppiced and *Eucalyptus* seedlings germinated in the study area; (ii) to compare the native and non-native species abundance, and diversity in the E. removal and non-E. removal sites; (iii) to assess the regeneration potential of *Alnus* species used as buffer zone in and out of the Gishwati side. The present study proposed the research questions related to the specific objectives:(i) what are the *Eucalyptus* stumps that are coppiced and E. seedlings germinated after their removal? ;(ii) what native and no-native species return post-*Eucalyptus* species removal, and what is their abundance and diversity indices on the removal sites within the study areas compared to non- E. removal sampled sites? (iii) what are the regeneration potential of *Alnus* species used as buffer zone in and out the Gishwati side?

CHAPTER 2. LITERATURE REVIEW

The deforestation, mining and invasion of exotic species (*Eucalyptus* sp, *Acacia melanoxylon, Acacia mearnsii* etc) at Gishwati and Mukura Forests led to land cover change and subsequently to landscape degradation and environmental deterioration (Mukashema, 2007). The forest of Gishwati, initially estimated to be 280 km^2 was reduced to only 7 km^2, which constitute a loss of 80 % of initial natural forest cover (Mukashema, 2007). This was accompanied with the loss of the chimpanze (*Pam Troglodytes*) and Golden Monkey (*Cercophithecus mitis Kandti*), as well as a number of bird species and indigenous tree species (Official et al., 2014).

The remaining Natural Forest Landscape supports an isolated population including chimpanzees (*Pan troglodytes*), thought to number between 19 and 29, golden monkeys (*Cercopithecus mitis kandti)* and L'Hoest's monkeys (*Cercopithecus lhoesti)* and more than 130 species of birds in Gishwati (Chancellor et al., 2012). In 1951, Mukura Forest Reserve was established with a total area of 2,000 hectares, but has now been reduced by encroachment of agriculture to about 1,200 hectares. The remaining patch of Mukura Forest hosts an interesting biodiversity, including a total of 243 plant species (Rwanda, 2011).

The baseline survey on the biodiversity carried out at Gishwati-Mukura National park has shown that the most abundant tree species in the park such as *Macaranga* , *Polyscias fulva, Symphonia globulifera, Carapa grandiflora and Syzygium guineense*, *Maesa lanceolata* and *Dombeya torrida* were identified in the two forests(Park, 2018). The common grass fodder species identified included *Isachne mauritiana* and *Coelachyne African*. The *Ipomoea involucrate, Embelia schimperi* were identified as the climbers. There was high diversity of *Drymaria cordata*, Impatiens species and *Asplenium friesiorum* herbs species. In the open disturbed area *Pteridium aquilinum*, *Vernonia spp* were highly abundant. The woody understory species such as *Mimulopsis arborescens, Mimulopsis solmsii, Mimulopsis excellens, Allophyllus chaunostachys , Clutia abyssinica*, were present.

The gramineous herbs species were highly occupied in the degraded zone. In the fertile soil, there was high presence of *Mimulopsis, Justicia* and hypoestes species. The *Triumfetta cordifolia* created a monospecific community and covering large area in the forest(Park, 2018). The family of Rubiaceae, like Pavetta, Galiniera species were observed in the understory of the

tall tree in the two forests. There was the occurrence of the secondary forest species such as *Macaranga capensis var. kilimandscharica and Maesa lanceolatae*, (non- shade tolerant species) once they made a closed canopy can allow the germination of shade tolerant species.
Macaranga capensis and *Maesa lanceolata* community: a typical secondary forest was identified in severely-disturbed areas of Mukura and Kinyenkanda section of Gishwati. The two tree species dominant in the community are known to grow only after primary forest clearing. They clearly indicate former severe disturbance but they also provide hope of accelerated forest regeneration. The presence of rare species like *Salacia erecta* and *Afrocrania volkensii* is also characteristic of this community demonstrating a potentially recovering forest (Report & Consultancy, 2017)

The research conducted at North America, where the exotic shrubs species removed to the native species regeneration proven that after post exotic species removal, there was more dense understory of native species and increased biodiversity regrown in the removal area (Maynard-bean et. al.,2019). The native species regenerated were categorized into herbs, shrubs, trees and climbers with the high abundance of herbs species (Maynard-bean et al., 2019). In Southern Western India, a study has proved that on the cleared *Eucalyptus* forest resulted the high abundance of native species regenerated with different states (adults, saplings and seedlings) brought by winds, animal and birds compare to the mature *Eucalyptus* plantation aged at 25 years (Selwyn & Ganesan, 2009).
In China, it was observed that under some *Eucalyptus and Pinus* species, the natural regeneration is inhibited due to allelopathy, allelochemical volatilization and foliage litter (Chu et al., 2014). The regeneration of native saplings under plantation seemed to vary depending on the species of over-story of exotic trees. For instance, some exotic over-story trees like *Casuarina equisetifolia* may inhibit the regeneration of native saplings (Loo et al., 2017).
Assisted natural regeneration was done in Nyungwe National Park in the burnt areas by cutting the fens (*Pteridium aquilinum*) in 2007 within plot to allow light to reach the ground, and the results showed that in the first years, new seedlings have appeared included *Macaranga kilimandscharica*, *Polyscias fulva* at Kitabi, Umugote, Gasare, and Mubuga plots site (Park N.N., 2007).

In Uganda, the logging of *Cypress* and *Eucalyptus* exotic species for the regeneration of indigenous species resulted the high regeneration of values species richness in a pit sawn area of *Cypress* and *Eucalyptus* at 75 and 55 than in unlogged plantations respectively (Kasenene, 2007). The intervention from LAFREC project removed the *Eucalyptus* species and assisted natural regeneration in the Gishwati-Mukura National Park on an estimated total area of 484 ha. The assisted natural regeneration method is referred to as Accelerated Natural Regeneration (ANR) which is a potentially rapid, efficient and cost effective means to reforest critical areas.

It involved planting of seedlings produced in a nursery, high germination cuttings in the removal site (Shono, Cadaweng, & Durst, 2007). ANR is a method for enhancing the establishment of secondary forest from degraded areas by protecting and nurturing the mother trees and their wildlings inherently present in the area. The native species that were used to regenerate the Gishwati Forest include *Polysias fulva, Podocarpus falcatus, Carapa grandiflora, Syzigium guineense, Parinari exselsa,* and *Croton macrostachyus*. The *Eucalyptus* species removal enhanced the natural regeneration of native species and improve the sun light to reach on the understory and ground, where the dormant native seeds can germinate (Karen & David, 2011).

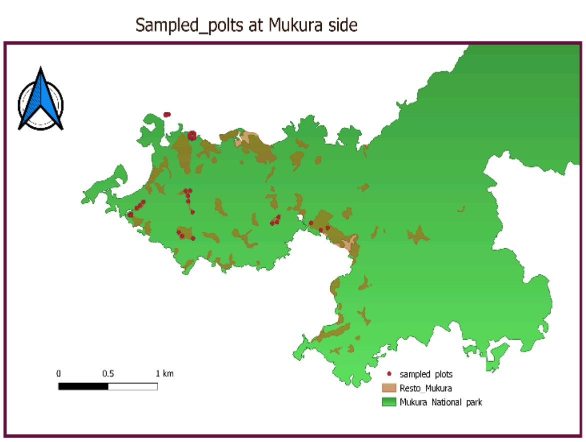
The seeds fallen on the ground receive the favorable conditions (light, moisture and growing medium) enabling seeds to germinated. The natural regeneration is important in the natural reserve management and it is a fundamental in the evolution of forest ecosystem. (Jónsson, 2016). The removal of *Eucalyptus* species in the Gishwati-Mukura National Park was done by cutting down trees, debark, remove the coppices and remove the E. stumps in some area of Mukura side to avoid the occurrence of the E. in the parks (Tuyishime, 2017). This research availed the data on number and what shade and non-shade tolerant species regenerated at post *Eucalyptus* species removal, species abundance and richness to the site to ensure functioning of the ecological services and products provision as an economic engine for the surrounding communities and fully community involvement in the protection of the park.

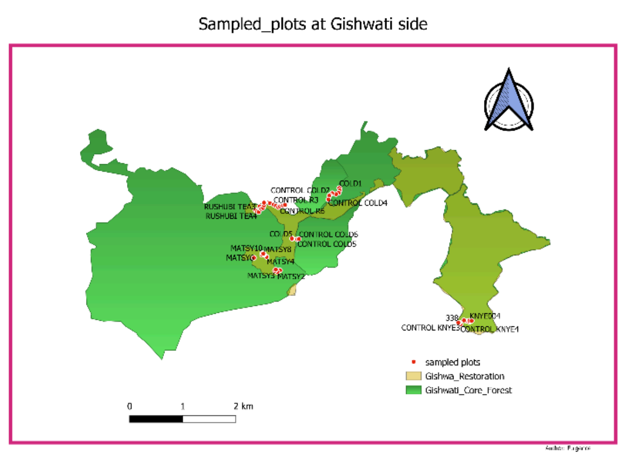
In addition, this provided the data of native and non-native species regenerated in Gishwati-Mukura National Park study sites to help the park management authority to take any other conservation measures to fully functioning of the park.

CHAPTER 3.MATERIALS AND METHODS

3.1. Study area location and characterization

The Gishwati-Mukura National Park is situated in north-west of Rwanda, between 29°21'40'' – 29°28'5'' East and between 1°36'52" – 1°52'17'' South with altitude ranging from 2000m to 3000m above sea level. The landscape has an averaged cool temperature of 10°C and mean annual rainfall of 1800 mm (Nyandwi & Mukashema, 2011). The umbrisol soil type of Gishwati-Mukura landscape formed from the decomposition of organic matter which enrich the soil in terms of soil nutrients (Kisioh, 2018). Mukura and Gishwati touch 4 districts, Rutsiro and Rubavu districts in west and Ngororero and Nyabihu districts in east (Nyandwi & Mukashema, 2011). Mukura is located within Rutsiro and Ngororero Districts. Much as these reserves are now detached, history shows that Mukura forest used to be attached to Gishwati and Nyungwe before agents of deforestation came (Tharcisse, 2014). Gishwati-Mukura landscape is bounded by cropland and the grazing areas and crossed by Pfunda River (Tharcisse, 2014). The research was conducted where the *Eucalyptus* tree species were removed by LAFREC project inside the park as shown on the maps below.





3.2. Dominant vegetation

A recent study of carbon sequestration of the forest indicated that *Macaranga kilimandscharica (*umusekera*)* is the most common tree species in Gishwati –Mukura National Park. Previously disturbed regions of the forest experiencing regeneration show colonization of

Carapa grandiflora (Umushwati), *Entandrophragma excelsum* (umuyove) and *Symphonia globulifera*. Other floras of the reserve include giant tree ferns and blue lichen (Kisioh, 2018). The assisted regeneration made composed by *Neoboutonia macrocalyx* and *Polyscias fulva*. Mukura Forest contains highly diversified and rich flora. Among its flora at least 243 plant species, the following are predominant: *Psychotria mahonii, Macaranga, Psydrax parviflora, Syzygium guineense, Rytiginia kigeziensis, Mutundu, Rapanea melanophroides,* lemonwood, *Peddiea rapaneoides, Galiniera saxifraga, Vernonia lasiopsis, Chassalia subchreata, Hagenia*, false assegai, *Olinia rochitiana, chewstick, lebekyet*, silky bark and *Vernonia kirungae*(Park, 2018).

3.3. Sampling design

Eucalyptus species was removed in Gishwati-Mukura National Park in 2015, where 63ha was in patches both in Gishwati and Mukura Landscape (Tuyishime, 2017). A purposive sampling method used to locate the *Eucalyptus* species removed and non-*Eucalyptus* removed areas. Thereafter, simple random sampling method used to locate the plots where each plot had equal probability of being selected to represent the population. The *Eucalyptus* species removed areas were identified together with the local peoples and randomization of 10m grid was done with Quantum Gis software.

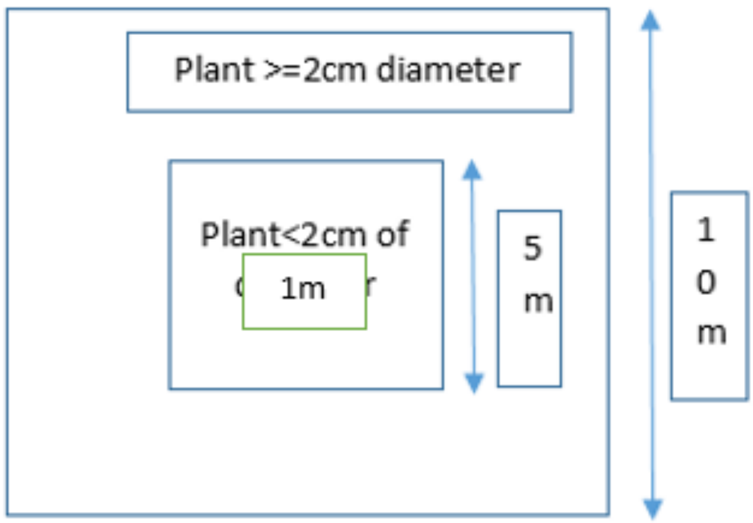
Sampling unit center was tracked with Global Position System (GPS) receiver after entering the geographical coordinates (longitude and latitude) in the GPS to define plot size of 10mx10m.

In the quadrat plots of 10mx10m exotic and native tree species having >= 2cm of Diameter at Breast Height (DBH) regrown was identified, counted and recorded on the field form.

In the big plot, a small quadrat plot of 5mx5m was for the counting and identifying exotic and natives plant species having DBH < 2cm regenerated in the study areas and for the herb layer data collected within

1mx1m. The controls were at non- *Eucalyptus* removed sites for each sample size (i.e. 10x10m, 5mx5m and 1mx1m).

Experiment design in the study areas



From the *Alnus* buffer 100m was measured from the edge toward outside and inside of the Park. The seeds and seedlings of *Alnus* species were collected at 0, 5, 15, 30, 50, 75 and 100m distance within quadrat of 1m in the study areas. A line had 7 quadrat plots which was replicated in 4 sampling areas(Vespa etal., 2018)

3.4. Sample size

The sample sites of *Eucalyptus* species removed area and no removal area of Kinyenkanda, Matyazo, Rushubi and Corridor of Gishwati side and Busoro, Rwungo, Rugaragara, Ndaba and Rucanzogera of Mukura side together with their control made 18 sampling sites which were used during the data collection. In each sampling site, we randomized 3 and 5 sampling plots at Mukura and Gishwati sides respectively. The total number of 74 sampling plots were randomized in 18 sampling sites during data collection.

3.5. Data collection

The species names (scientific and vernacular) were identified whether the plant species is native or exotic by using Fischer & Killmann (2008) and the Plant List Database.

Number of stems present on the study sites which help us to know the species density, richness and evenness and the life form of plant species to differentiate the tree, shrubs and herbs species regenerated after exotic species removal were collected within 10mx10m, 5mx5m and 1mx1m plot sizes.

3.6. Data analysis

The shade and no shade tolerant tree species, herbs species abundance, Shannon diversity index (H') and evenness index (J) in the study areas (*Eucalyptus* species removed and control) were analyzed in the excel sheet with pivot table and bio professional software. The comparative graphs of E. stumps coppiced, E. seedlings, number of *Alnus* seeds and *Alnus* seedlings were analyzed with excel sheet.

CHAPTER 4. RESULTS

4.1. The number of *Eucalyptus* stumps, E. stumps coppiced and *Eucalyptus* seedlings

The 17 plots in the *Eucalyptus* removed area of Mukura side, a total number of 81 *Eucalyptus* stumps counted, 8 *Eucalyptus* stumps were coppiced (Fig.1). The high number of E. stumps coppiced were located at Busoro2 compare to Rugaragara and Rwungo sites which had none E. coppiced stumps.

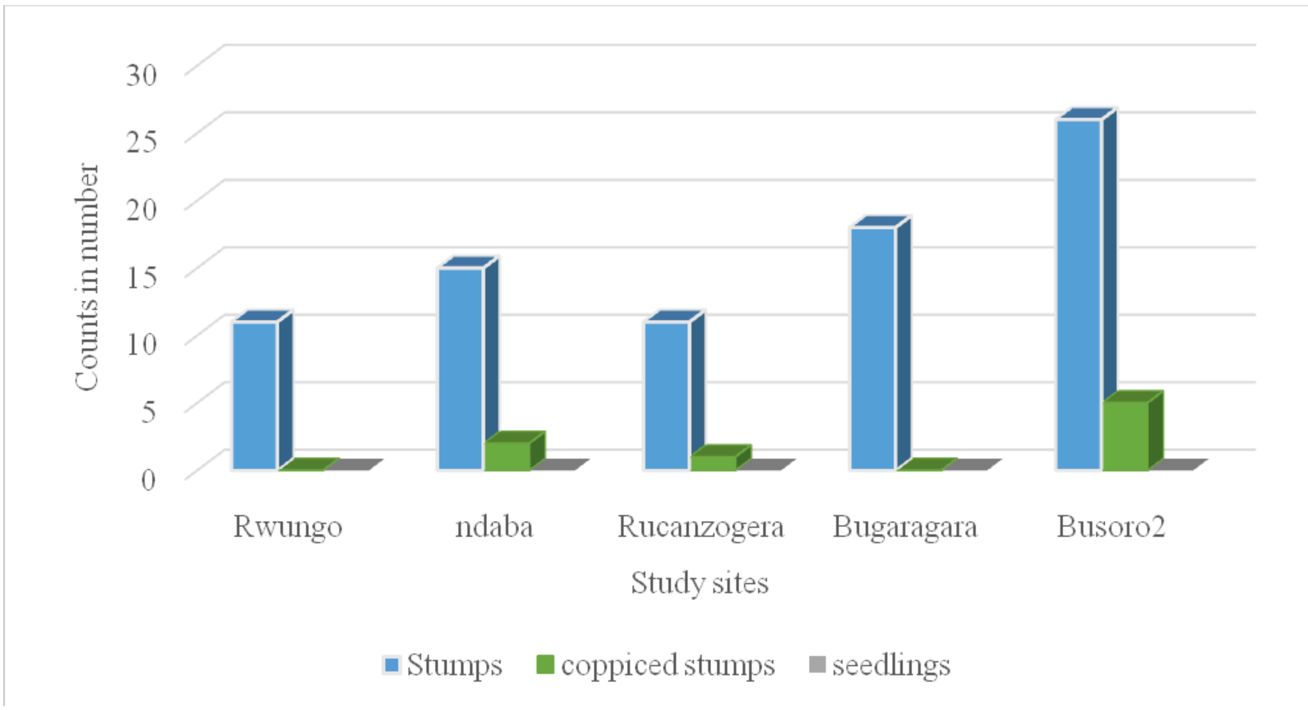


Figure 1: The number of *Eucalyptus* stumps, E. stumps coppiced and *Eucalyptus* seedlings counts at Mukura side.

The number of E. stumps, E. stumps coppiced and E. seedlings were recorded within 25 m^2 (quadrat of 5mx5m) at Rwungo, Ndaba, Rucanzogera, Rugaragara and Busoro2 sites. The were no E. seedlings germinated in the area.

The 4 study sites of Gishwati include Matyazo, Rushubi, Corridor and Kinyenkanda sites, a total number of 116 *Eucalyptus* stumps with 12 E. stumps coppiced were identified. This was due to the improper stump debarking done on some stumps. Only 3 E. seedlings germinated in the whole study sites of Gishwati were recorded **(**Fig.2**)**. The high number of E. stumps coppiced were recorded at Rushubi and Matyazo at 6 and 5 stumps coppiced respectively compare to Kinyenkanda which had none E. stumps coppiced.

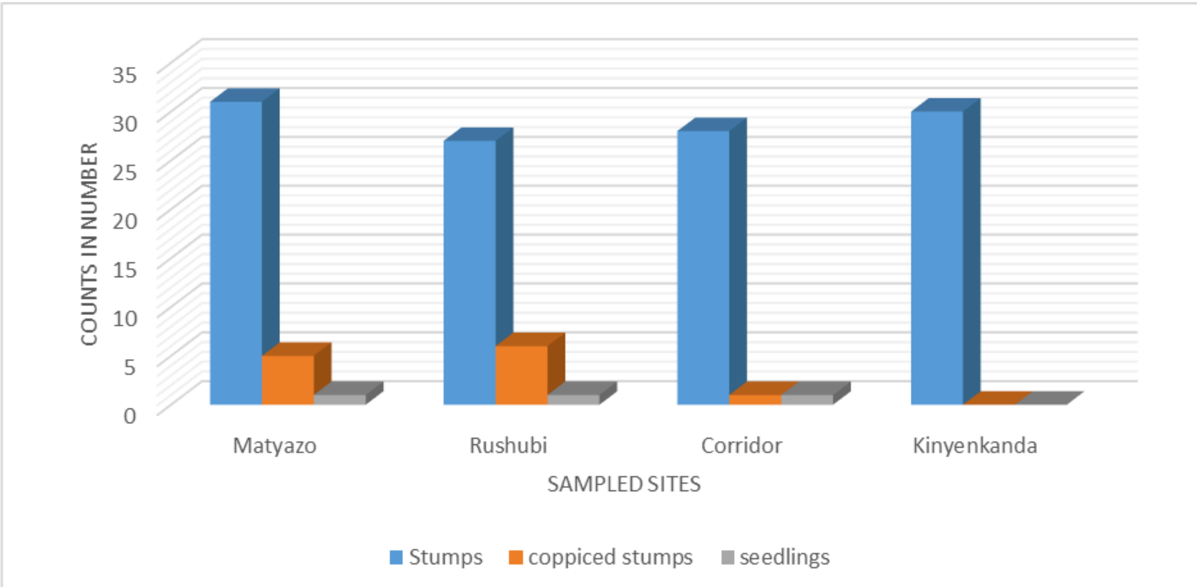


Figure 2: The number of E. stumps, E. stumps coppiced and E. seedlings counts at Gishwati side

The number of E. stumps coppiced was low due to the debarking and the stumps management activities done after the tree cutting, except at Rushubi and Matyazo sites some stumps were not debarked and did not receive any stumps management activity which caused a number of 6 and 5 stumps coppiced respectively.

4.2. Regeneration potential of *Alnus* species inside and outside of the Gishwati side.

A portion of Gishwati buffer zone is made by *Alnus* species. The *Alnus* tree seeds movement inside and outside of the Park were driven by different factors. The total estimated number of *Alnus* seeds was 606 at both inside and outside of the Park with the high number of seeds at 0 and 5 m distance while at 100m distance there was no seed (Fig 3). A total of 77 *Alnus* seedlings were counted outside the parks in pasture land and none seedlings inside the park (Fig. 4).

The number of seeds distributed alongside of the line decreased as the distance increased.

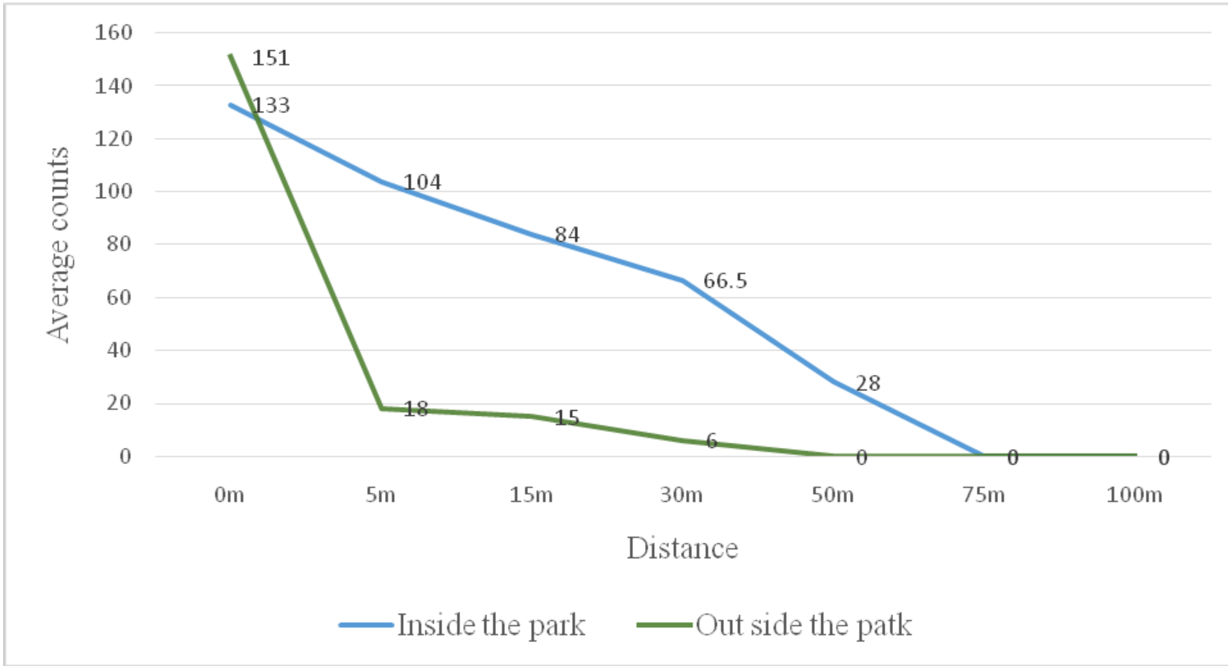


Figure 3:The *Alnus* seeds distribution inside and outside of the Gishwati

The number of *Alnus* seeds decrease as you go far from the *Alnus* tree stump.

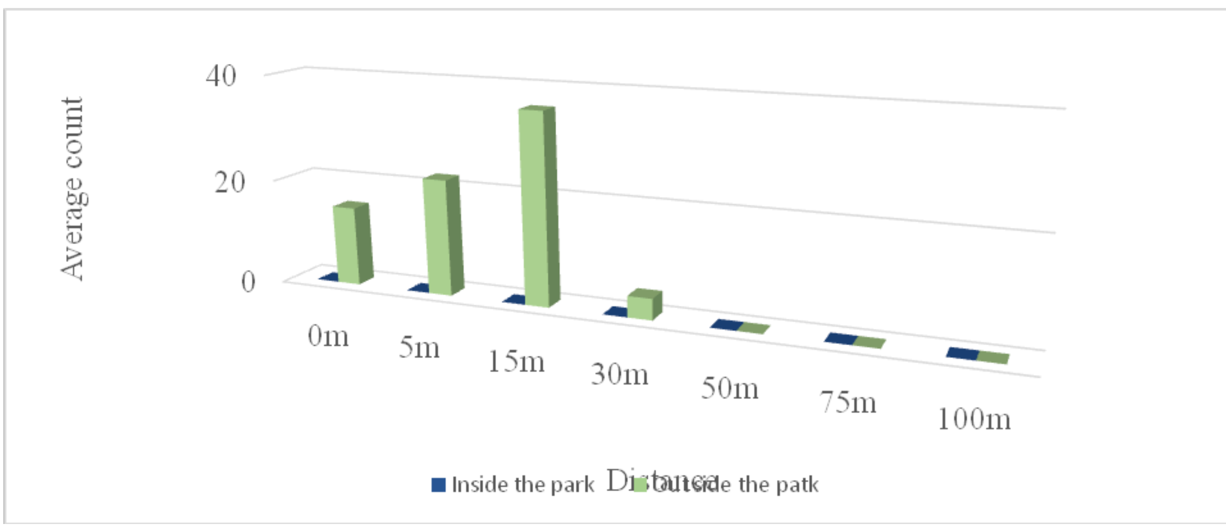


Figure 4: Abundance of *Alnus* seedlings germinated inside and outside of Parks.

The number *Alnus* seedlings increased within the first 15 meters and decrease to the zero from 50 m and above in the outside of the park due to the favorable condition that seeds reached after falling while inside the park the germination condition of *Alnus* seeds did not favor the seeds to germinate, where there was none seedling counted inside the park.

4.3. Abundance of native herbs species in the *Eucalyptus* removed and none removed areas.

4.3.1. Native herbs species in the study area

The total number of 1466 and 1246 herbs species were identified at Gishwati and Mukura sides respectively. The highest number of herb species were collected at Matyazo and the lowest at Corridor control of Gishwati side. At the Mukura side, the high abundance of herbs species recorded at Rwungo and low number at Ndaba control. The *Coelachne africana and Phyllanthus nummulariifolius* were mostly dominant herb species in both sides (Appendix 9 and 10).

4.3.2. The abundance of native and non-native woody species in the study area

The total number of woody species (shrubs and tree) identified was 380 native and 76 exotic woody species at Gishwati side. Among the exotic woody species identified, the *Eucalyptus* was dominant because it was recorded in the controls and few number in the E. removed sites. The *Macarananga kilimandscharica* dominated other native woody species as it is the first growth species in the disturbed area (Park N.N., 2007)(Fig.5).

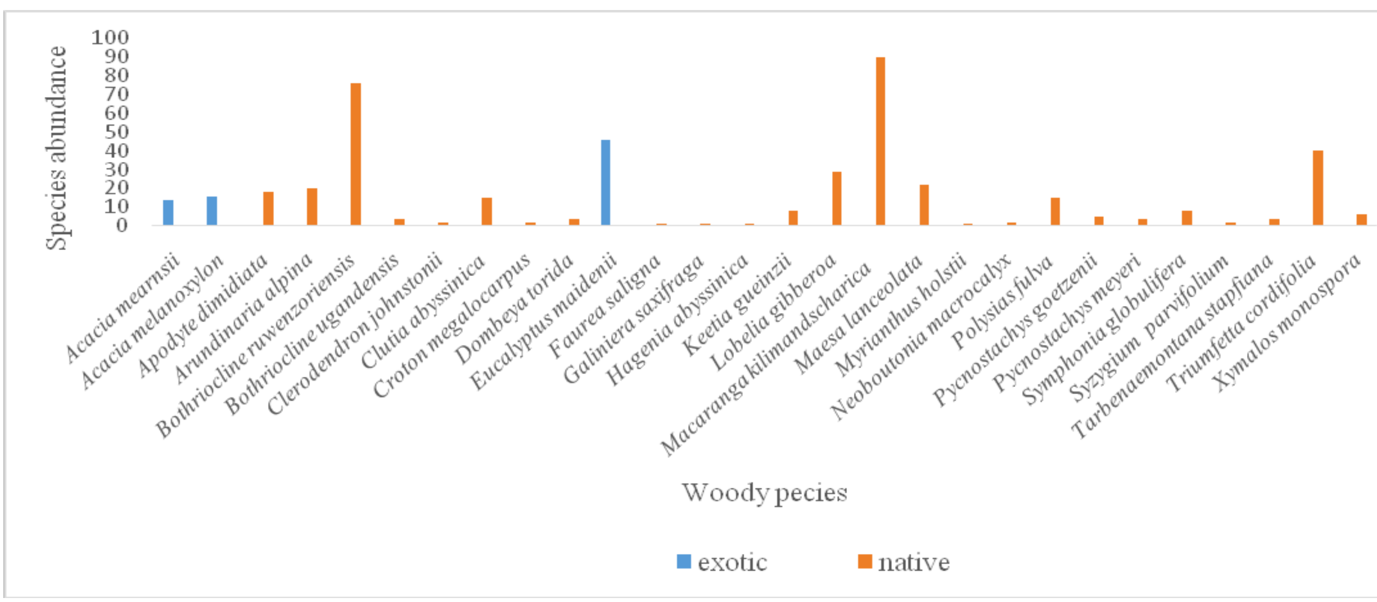


Figure 5: Comparison of the native and non-native woody species at Gishwati side

The non-shade tolerant species identified were conquered by *Macaranga kilimandscharica, Maesa lanceolata, Bothriocline ruwenzoriensis,* compared to shade tolerant species like *Symphonia globulifera*, *Syzygium guiness,* and *Hagenia abyssinica.* Some shade and non-shade tolerant woody species recorded were planted during assisted natural regeneration to quick recovery of the degraded area.

At Mukura, a total number of 378 native woody species and 33 non-native woody species of 29 different species were identified. The side was highly dominated by *Triumfetta cordifoli* (umusarenda) native woody species which is distributed in cleared area (Fischer & Killmann, 2008), and *Eucalyptus maidenii* non-native species. The area had the mature *Grevillea robusta* and *Cuppressus lusithanica* (Fig.6).

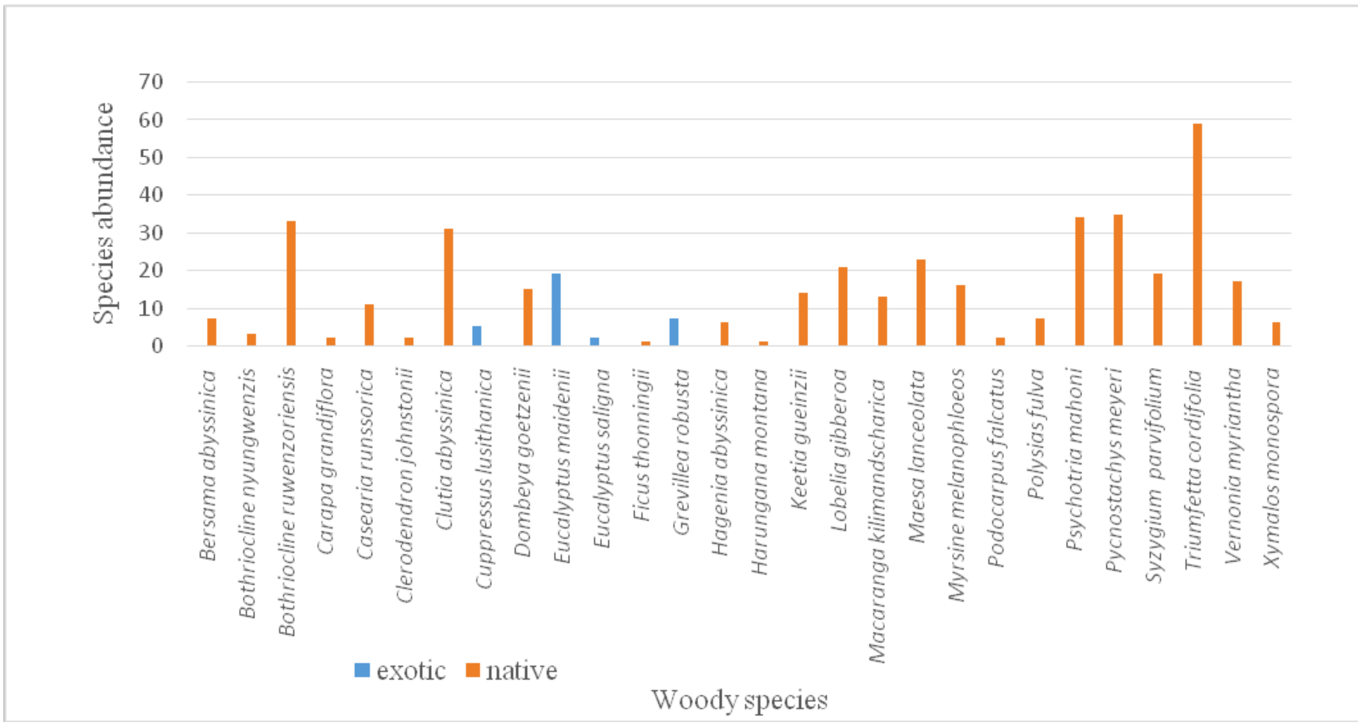


Figure 6: Comparison between native and non-native woody species at Mukura side

The secondary forest, non-shade tolerant species such as *Maesa lanceolata*, *Macaranga kilimandscharica,* were observed at the low rate compared to *Pycnostachys meyerie* and *Bothriocline* species. The shade tolerant species was identified with high dominance of *Syzygium guinenensis ssp. parvifolium* (Fig.6).

4.3.3 Diversity index and similarities of plant species in the Gishwati-Mukura National Park

At Gishwati side, the Shannon diversity for the herbs species was higher in the Corridor site while the Matyazo sites was small (Table 1). In the study sites of Mukura side, Shannon diversity was high at Busoro2, followed by Rwungo and the smallest was observed at Ndaba control (Table 2). At Gishwati, the highest similarity of the herbs species abundance was observed amongst Rushubi control and Matyazo control (55.62%) followed by the similarity between Corridor and Kinyenkanda (55.31%) (Fig.7; Appendix3). At the Mukura side, the highest similarity was observed between Rugaragara control and Ndaba control (70.97%) and the similarity between Rugaragara and Rucanzogera was (60%) (Fig.8; Appendix4).

Table 1:Shannon diversity index and evenness for the herbs species in 8 study sites of Gishwati side(July 2019).

Index	Corridor	Corridor control	Kinyenkada control	Kinyenkanda	Matyazo	Matyazo control	Rushubi	Rushubi control
Shannon H' Log Base 10.	1.004	0.803	0.754	0.794	0.728	0.847	0.947	0.749
Shannon Hmax Log Base 10.	1.279	0.903	0.903	0.954	1.114	1	1.204	0.903
Shannon J'	0.785	0.889	0.835	0.832	0.654	0.847	0.786	0.829

Table 2: Shannon diversity index and evenness for herbs species from 10 studies area of Mukura side (July 2019).

Index	Busoro2	Busoro 2 control	Ndaba	Ndaba control	Rucanzogera	Rucanzogera control	Rugaragara	Rugaragara control	Rwungo	Rwungo control
Shannon H'	1.275	0.789	1.01	0.713	1.032	0.776	0.963	0.73	1.176	0.74
Shannon Hmax	1.38	0.954	1.11	0.778	1.114	0.845	1.114	0.845	1.38	0.84
Shannon J'	0.924	0.827	0.91	0.916	0.926	0.919	0.864	0.864	0.852	0.87

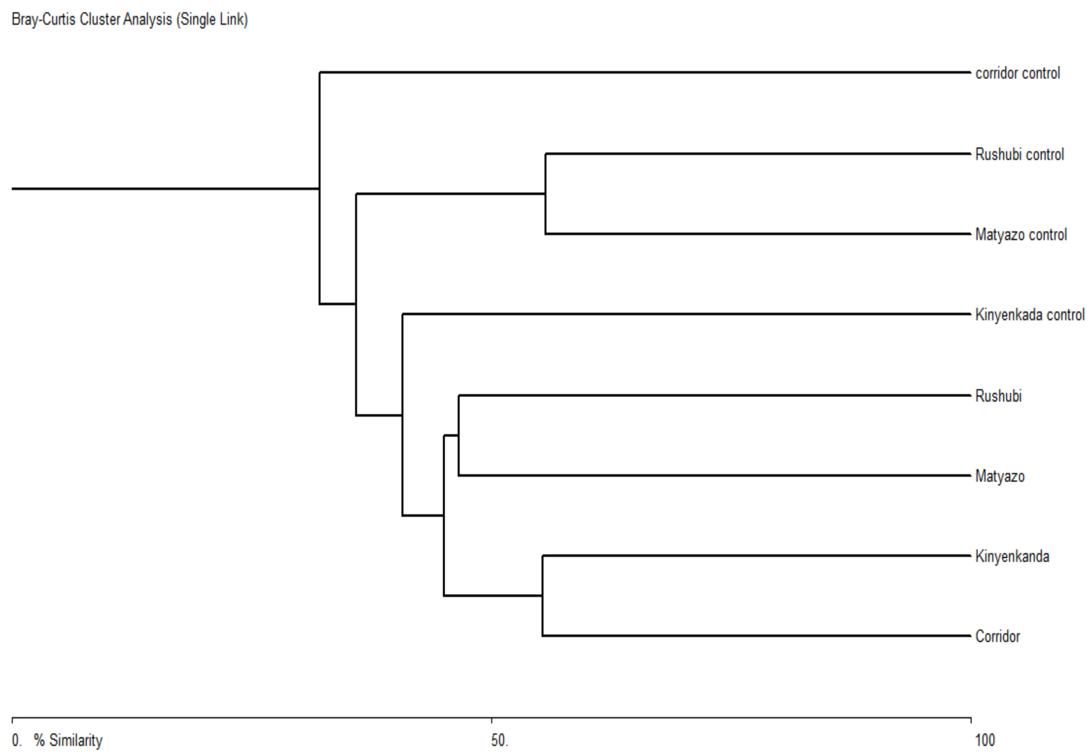


Figure 7: Herbs species similarity within 8 study sites in relation to their richness in the Gishwati side.

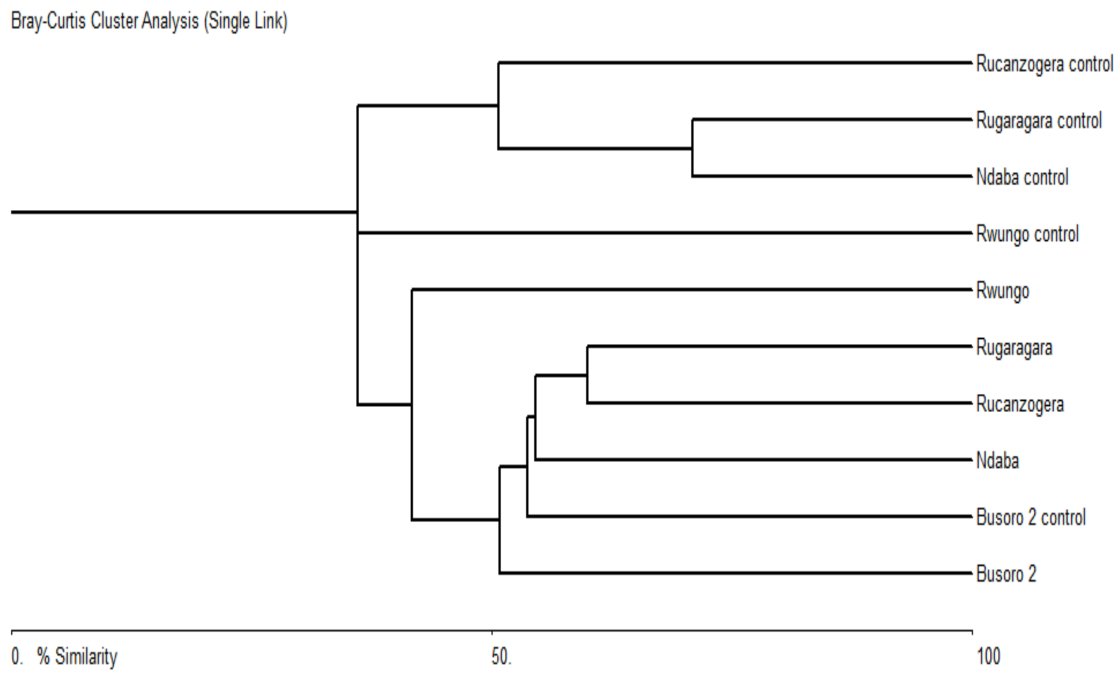


Figure 8: Herbs species similarity within 10 study sites in relation of their richness in the Mukura side

For the woody species (shrubs and trees) identified at Gishwati side the high Shannon diversity was observed at Matyazo followed by Rushubi and the smallest was Matyazo control (Table3). The sites of Mukura side, the maximum Shannon diversity was observed at Busoro2, and the small Shannon diversity was at Rwungo control (Table 4). In the Gishwati study sites the topmost similarity of the woody species abundance was observed between Corridor control and Matyazo control (90.54%) and followed by the similarity between Rushubi control and Matyazo control (70.68) (Fig. 9; Appendix 7). Where at Mukura side, the highest similarity was observed between Busoro2 control and Ndaba control (95.77%) and then the similarity between Ndaba control and Rugaragara control (95.38%) (Fig.10; Appendix 8).

Table 3. Shannon diversity index and evenness for woody species from 8 studies areas of Gishwati side (July 2019)

Index	Corridor	Corridor control	Matyazo	Matyazo control	Kinyenkanda	Kinyenkada control	Rushubi	Rushubi control
Shannon H' Log Base 10.	0.316	0.161	0.334	0.128	0.262	0.224	0.326	0.175
Shannon Hmax Log Base 10.	3.178	1.946	3.332	1.609	2.773	2.485	3.258	2.079
J'	0.099	0.083	0.100	0.080	0.095	0.090	0.100	0.084

Table 4. Shannon diversity index and evenness for woody species from 10 studies area of Mukura side (July 2019).

Index	Rugaragara	Rugaragara Control	Busoro2	Busoro2 control	Ndaba	Ndaba control	Rucanzogera	Rucanzogera control	Rwungo	Rwungo contro
Shannon H'.	0.2797	0.1629	0.35	0.182	0.25	0.172	0.2111	0.1487	0.24	0.04
Shannon Hmax.	4.3694	3.4340	5.05	3.610	4.18	3.526	3.8501	3.2958	4.12	1.79
J'	0.0640	0.0474	0.07	0.050	0.06	0.049	0.0548	0.0451	0.05	0.02

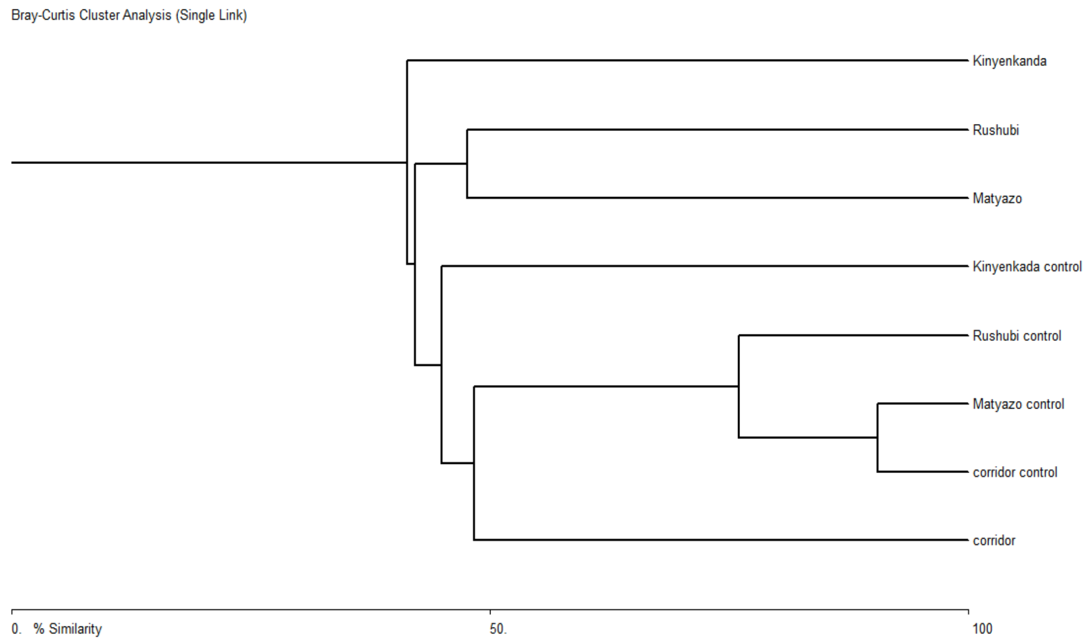


Figure 9: Woody species similarity within 8 study sites in relation to their richness in the Gishwati side.

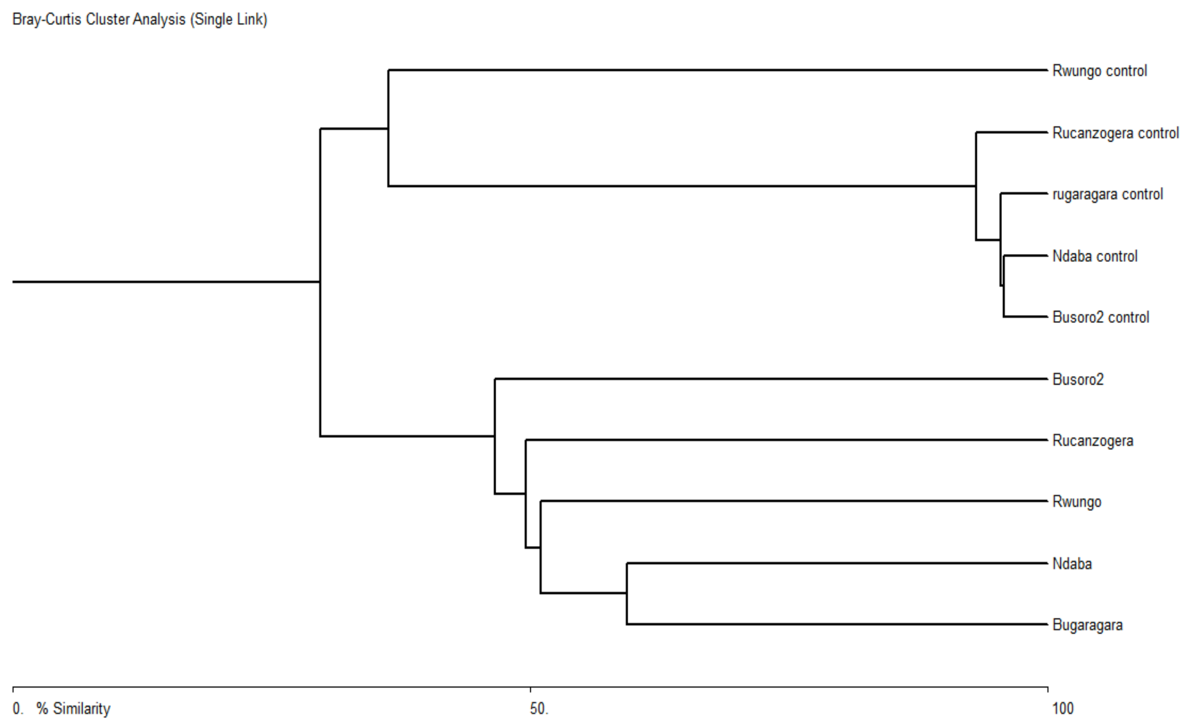


Figure 10: Woody species similarity within 10 study sites in relation to their richness in the Mukura side.

The rarefaction curves were used to compare the herbs species richness in Gishwati-Mukura National Park (Fig. 11 and 12). Corridor site is the most diverse followed by Rushubi site of Gishwati side. Mukura side, Busoro and Rwungo were the most diverse while the Ndaba control was the least diverse (Fig. 11and 12; Appendixes 1 and 2).

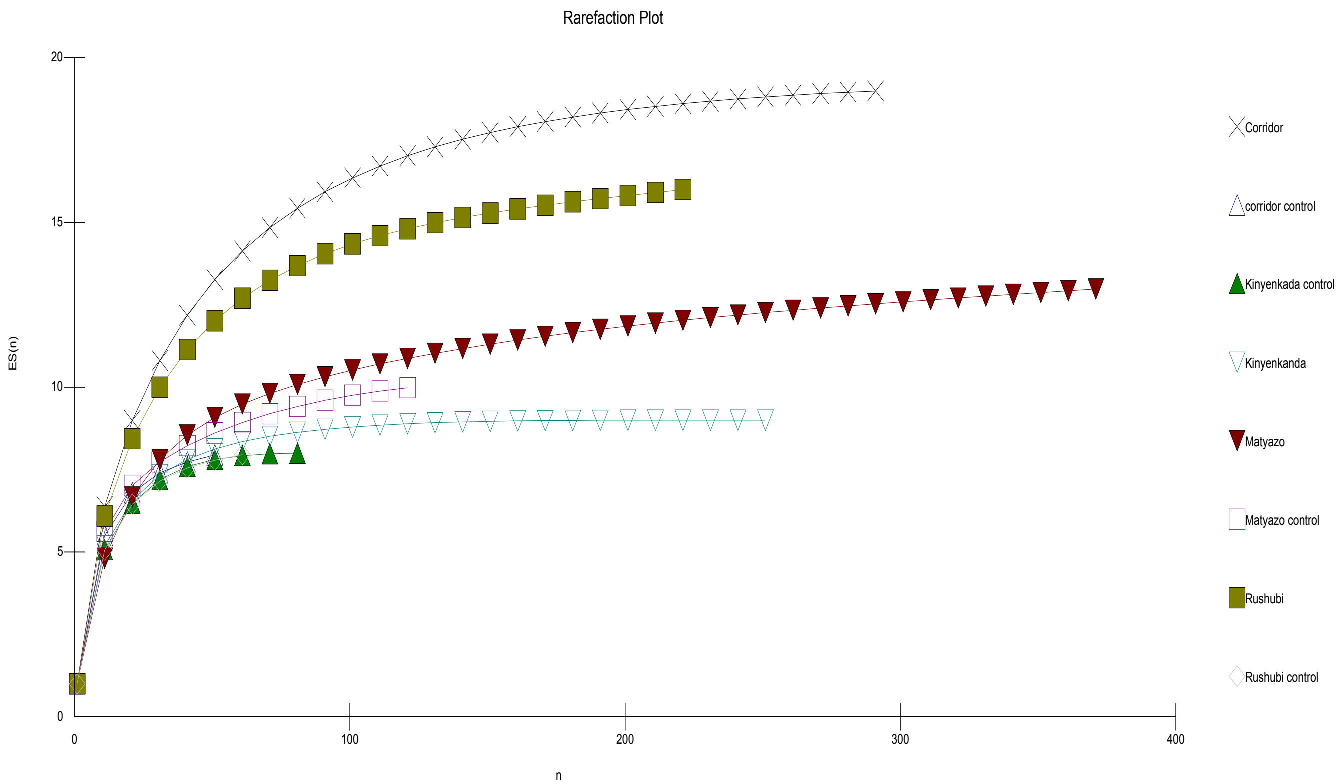


Figure 11. Rarefaction curve for the abundance of herbs species in 8 study sites of Gihwati side.

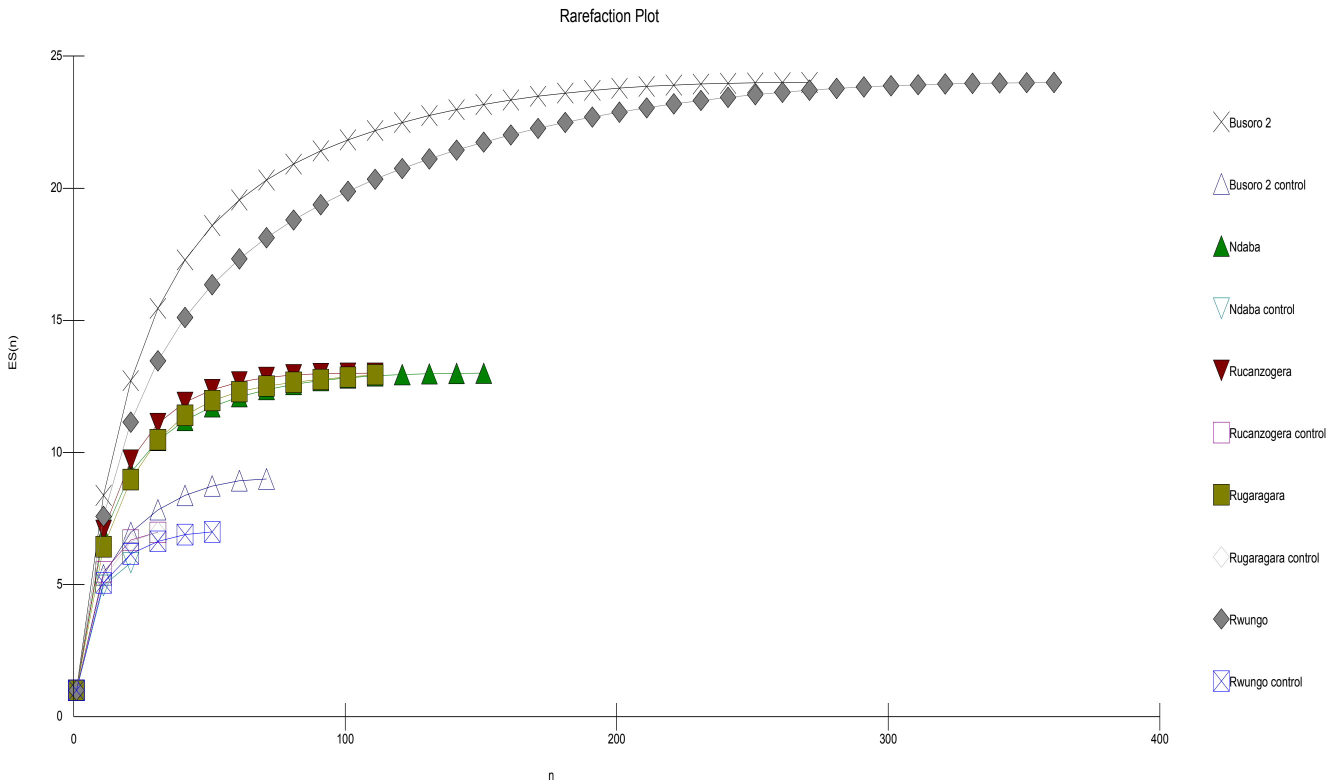


Figure 12. Rarefaction curve for the abundance of herbs species in 10 study sites of Mukura side.

For the woody species identified at different sites of Gishwati-Mukura National Park, the rarefaction curves showed the high richness woody species at Rushubi and followed by Matyazo of Gishwati side. Mukura side, Rugaragara and Busoro2 were highly diverse (Fig. 13and 14; Appendixes 1 and 2).

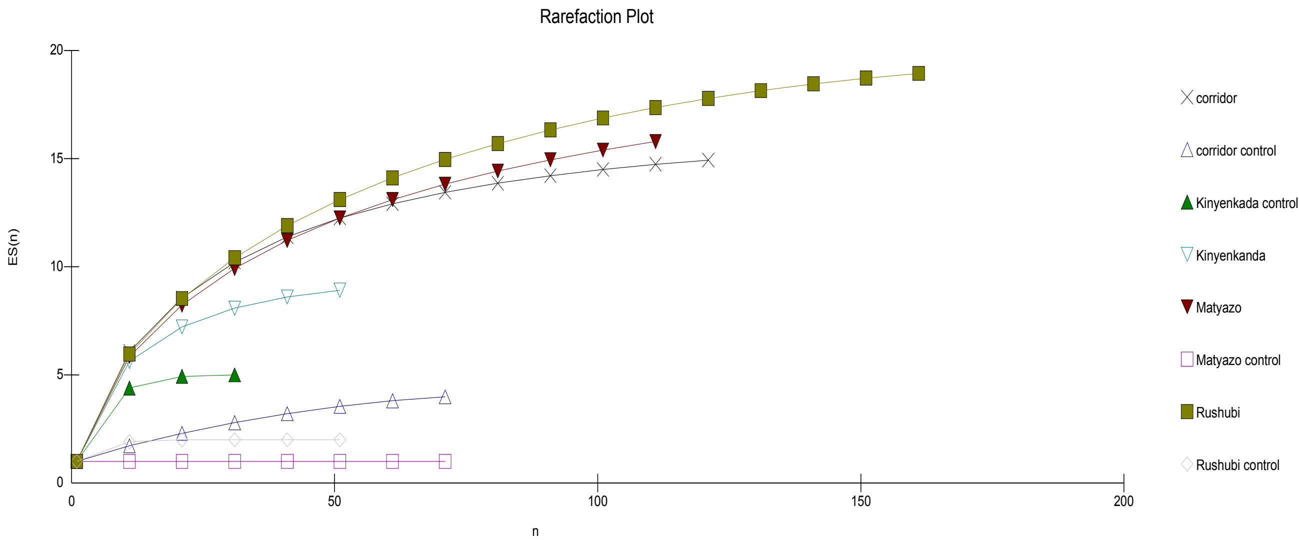


Figure 13: Rarefaction curve for the abundance of woody species in 8study sites of Gishwati side.

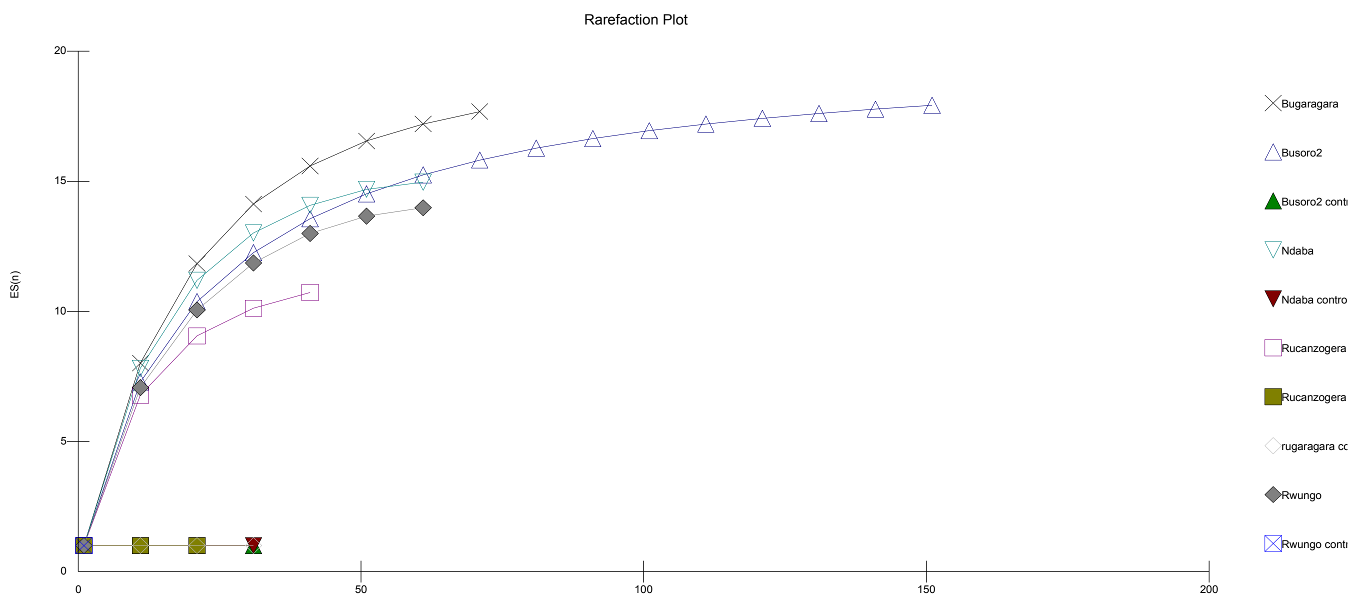


Figure 14:Rarefaction curve for the abundance of woody species in 10 study sites of Mukura side.

CHAPTER 5. DISCUSSION

5.1. Number of *Eucalyptus* stumps, *Eucalyptus* stumps coppiced and *Eucalyptus* seedlings

The *Eucalyptus* species removal in the Gishwati-Mukura National Park was done in 2016, and after 3 years total number of *Eucalyptus* stumps coppiced was 12 within 116 number of stumps identified at Mukura Gishwati side and 8 coppiced stumps out of 81 stumps at Mukura side (Fig.1 and 2) which were representing 10.3% and 9.8% respectively. This may be explained by the stumps debarking level and none debarked E. stumps which was followed by the several wood decaying fungi which attacked the stumps (Alonso et al., 2012). These results are comparable to what has been obtained by Alonso et al. (2012) who conducted the research on the development of the sprouted stumps of *Eucalyptus maidenii* and *Eucalyptus globulus* under different level of stumps debarking and they got 12.5% sprouted stumps that were still alive. The harvesting method, seasons (summer and winter), age of stumps, period stumps stay after cut and stumps damage had the high influence on the regeneration or coppicing of E. stumps ability (Daniel Pegoretti Leite de Souza, 2015). According to Alonso et al. (2012) the incidence of bark detachment decreases the number of the coppiced stumps, where no barks detachment resulted 100% of coppiced while 100% barks detachment resulted in 0% of the stumps coppiced. The rotting fungi can cover the whole surface of the E. stumps after the period of two years' harvest.

5.2. Number of *Alnus* seeds dispersed and seedlings germinated

The number of *Alnus* seeds counted was significantly decreased from the nearest of the tree stumps to 100m distance, whereas inside the park, 133 seeds were counted near the stump and none seed recorded at 75m (Fig. 3), this was due to the wind and gravity forces that pull out the seed of *Alnus* in the study area and the other displacement factors including the human being looking for the seeds for tree plantation (by human observation). The *Alnus* seed are winged that can be transported by wind and birds at the long distance (Cunnings et al., 2016).

The number of *Alnus* seedlings ranged at 15 to 36 seedlings which were recorded at 0 m to 15 m distance in the outside of the park respectively due to the ground disturbance, the soil exposed and the shading effect described as the conditions affecting the *Alnus* seed germination in the protected area (Tobita et al., 2015).

Thought inside the park there were high seedbank, there was no seed germinated due to the shading effect and no soil exposed. This result is in line with what Tobita et al., (2015)got during the analysis of the regeneration of 23 woody species including *Alnus* species where they recorded 0% of *Alnus* (alder) seedling on the forest flow and *Alnus* seeds did not germinate on the covered or mulched land, but germinated well in the cleared land (Anderson, 2014).

5.3. Native plant species diversity and richness in in the *Eucalyptus* removed area

The number of the herbs species identified in the E. removed site and in the control were significantly different in all study sites with 1142 in E. removed area and 324 in the control of Gishwati side and 1019 and 227 species number at Mukura side respectively (Table1 and 2). The big difference in term of herb species abundance is explained by the chemical substance in the E. leaves which cause the allelopathic effect on the native species, the shading effect and high competition with native species in the area (Chu et al., 2014), and the E. species harmed the native species which caused the extinction of the native species as well as decrease native species population size(Dyer, 1996). This is similar to Kasenene (2007)observation after the assessment of the number of native species return in the E. logged area and they observed the high number of native species regenerated in the harvested area compared to the unlogged area. Kasenene (2007) also found the high diversity of the pioneer species, and the secondary forest after the *Eucalyptus* harvesting with the high regeneration of native species was at 80%. In the harvested area shown the high regeneration of native species at 106% compare to 14.4% regenerated to unharvested area (Barua et al., 2017). The regeneration of the native species in the nature area required the sun light to reach on the ground, growth medium (soil) and viable seed to germinate (Park N.N., 2007). The seed dispersal factors (wind, bird, animal, etc) are also taken into consideration to high abundance and diverse plant species in the disturbed area due to the different seed treatment provided (Isabel & Pinto, 2018).

The woody species regenerated in the E. removed site and non-removed site were 380 natives and 76 non-natives and 378 natives and 33 non-native woody species were identified at Gishwati and Mukura sides respectively. There were high abundance of pioneer species than climax species, the pioneer species including *Macaranga kilimandscharica, Maesa lanceolata, Dombeya torida, Bothriocline ruwenzoriensi*, *Xymalos monospora, Apodytes dimidiate*, etc and some climax species like *Carapa grandiflora*, *Podocarpus falcatus, Syzygium guinense,* and *Myrianthus holstii* .The results also were in the line with what Kasenene (2007) observed on species regenerated on pre- and post-harvesting of tree species, whereas in the E. harvested area resulted the high number of pioneer tree species regenerated compared to climax tree species after seven years. Selwyn & Ganesan (2009) found high diversity of saplings regenerated in the cleared area at 88% compared to 54% saplings of non-cleared forest.

5.4. Plant species variability in the *Eucalyptus* removed area and the control of the study site

The plant species abundance in the E. removal and control sites of Mukura side varies within the plots. The report presented at Gishwati side, Corridor had high plant species abundance than Kinyenkanda control and Corridor control. At Mukura side, the plant species were highly abundant at Busoro 2 and Rwungo sites than Rwungo control and Rugaragara control (Appendixes 1and 2). These results are comparable to what Selwyn & Ganesan (2009) got by which the native species abundance in the cleared *Eucalyptus* plantation was 100 compare to 58 individual counts in the un-cleared E. plantation. Moreover, the E. removed sites were open and disturbed by the human activities which lead to the high growth of the understory compared to the covered ground. Fischer & Killmann (2008) noted that plants of Nyungwe National Park Rwanda, shown the high number of plants species identified in Gishwati-Mukura National Park distributed on the forest edge, open and disturbed areas. At Gishwati side, Corridor was highly diversifying at (Hmax = 1.279) with the high abundance of H'= 1.004 compare to other sites, this is due to the minimum soil surface disturbance and low colonization of *Pteridium aquilinum* (Tab 1). The Busoro2 and Rwungo had high diversity (Hmax= 1.38) with different herbs species abundance due different frequency of the species present in both sites, H'= 1.275 and H'= 1.176 (Tab.2). The matrix of similarity in the 8 study sites of Gishwati side, was described by the dendograms which is illustrating the similarities between E. species removed area and the control at Gishwati, Rushubi control and Matyazo control had high similarity due to the most present species for both sites were the same (Fig.7). At Mukura side, the great similarity was observed between Rugaragara control and Ndaba control. This is because the species present were all most the same even if the species abundance were nearly equal (Fig.8).

CONCLUSION AND RECOMMANDATIONS

The assessment of the impact of removing the *Eucalyptus* species on the nature regeneration of native species at Gishwati_Mukura National Park showed how plant species diversity and abundance were mostly distributed based on presence or absence of *Eucalyptus* on the study sites. The research detected that there were low E. stumps regenerated compared to the total number of the E. stumps and the regenerated stumps found that they did not debark and not managed the sprouted trees. The Eucalyptus seedlings in the study area also were few due to the unfavorable condition enabling them to germinate. The second question was about the number of native and non-native species return after E. species removal, their abundance and richness, the research detected the bigger difference between the plant species regenerated in the E. removed sites and the non-E. removed sites. The *Coelachne africana, Phyllanthus nummulariifolius* herbs and *Macaranga kilimandscharica, Maesa lanceolate* woody species were highly abundant in the E. removed sites of Gishwati_Mukura National Park and few of climax species like *Syzygium guinens*. Those species indicated the highly disturbed areas and woody plants were mostly regenerated first (pioneer species) then low abundance of the climax species on the cleared forest. The dendrograms shown that the study sites similarities of the plants species abundance and diversity varied significantly within the study sites of Mukura and Gishwati sides. The plant species were not distributed equally through the study sites of the Park, due to there was high abundance of the plant species in the E. removed sites than none E. removed sites. Moreover, the E. removed sites shown high plant richness compared to non-E. removed sites. The last question was about regeneration potential of *Alnus* species used as buffer zone of Gishwati side in and out the Park, the results shown that the *Alnus* seed was highly decreased far from the tree stump in and outside of the park caused by some seeds dispersal factors including wind and gravity. There was no *Alnus* seedlings germinated inside the parks while the outside in the pasture land the number of seedlings germinated was in the 15 m due to the favorable environmental condition enabling the seed to germinate were there during research (soil exposed, light and favorable humidity).

Based on the research findings, we recommend to the researchers in the biodiversity department to study on the effect of the *Acacia melanoxylon* trees species on the native species abundance and distribution at Gishwati-Mukura National Park. It is also needed to study the seasonal variability effect on the native species regeneration in the *Eucalyptus* removed sites at Gishwati- Mukura National park to see the effect of sun and rainfall effect on the regeneration. Lastly we recommend the researchers in soil sciences to conduct a study on the effect of the Exotic species on the soil properties modification toward the native species distribution and abundance in the Park, which will help the park managers to take a proper decision toward the exotic species management in the park for the ecosystem functioning and the park integrity.

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APPENDICES

Appendix 1: Statistical summary of the herbs species at Gishwati side

Sample	Mean Individuals	Variance	Standard Deviation	Standard Error	Total Individuals	Total Species
Koridoro	7.171	258.695	16.084	2.512	294	19
Koridoro control	1.317	11.372	3.372	0.527	54	8
Kinyenkada control	2.024	34.474	5.871	0.917	83	8
Kinyenkanda	6.146	276.378	16.625	2.596	252	9
Matyazo	9.146	1015.478	31.867	4.977	375	13
Matyazo control	3	52.95	7.277	1.136	123	10
Rushubi	5.39	166.744	12.913	2.017	221	16
Rushubi control	1.561	20.452	4.522	0.706	64	8

Appendix 2: Statistical summary of the herbs species at Mukura side

Sample	Mean Individuals	Variance	Standard Deviation	Standard Error	Total Individuals	Total Species
Busoro	0.929	1.044	1.022	0.158	39	24
Busoro control	0.405	0.979	0.989	0.153	17	9
Ndaba	0.571	0.983	0.991	0.153	24	13
Ndaba control	0.262	0.539	0.734	0.113	11	6
Rucanzogera	0.476	0.695	0.833	0.129	20	13
Rucanzogera control	0.31	0.609	0.78	0.12	13	7
Rugaragara	0.476	0.695	0.833	0.129	20	13
Rugaragara control	0.214	0.319	0.565	0.087	9	7
Rwungo	0.905	0.966	0.983	0.152	38	24
Rwungo control	0.286	0.551	0.742	0.114	12	7

Appendix 3: Similarity Matrix of herbs species at Gishwati side

	Corridor	Corridor control	Kinyenkada control	Kinyenkanda	Matyazo	Matyazo control	Rushubi	Rushubi control
Corridor	*	13.79	14.32	55.31	36.17	13.43	45.05	13.97
Corridor control	*	*	32.12	17.65	14.45	16.95	25.45	30.51
Kinyenkada control	*	*	*	7.16	15.72	35.92	40.79	24.49
Kinyenkanda	*	*	*	*	38.60	9.07	42.28	15.82
Matyazo	*	*	*	*	*	10.44	46.64	10.02
Matyazo control	*	*	*	*	*	*	16.28	55.62
Rushubi	*	*	*	*	*	*	*	16.14
Rushubi control	*	*	*	*	*	*	*	*

Appendix 4: Similarity Matrix of herbs species at Mukura side

	Busoro2	Busoro2 control	Ndaba	Ndaba control	Rucanzogera	Rucanzogera control	Rugaragara	Rugaragara control	Rwungo	Rwungo control
Busoro2	*	24.49	43.97	2.66	47.52	12.26	50.90	5.94	41.76	24.00
Busoro2 control	*	*	40.18	13.73	40.22	36.04	53.68	21.15	15.53	28.57
Ndaba	*	*	*	14.29	54.55	28.27	49.63	18.48	30.89	35.92
Ndaba control	*	*	*	*	23.94	49.28	5.41	70.97	6.57	4.76
Rucanzogera	*	*	*	*	*	34.44	60.00	27.78	33.47	34.94
Rucanzogera control	*	*	*	*	*	*	24.20	50.70	10.86	25.81
Rugaragara	*	*	*	*	*	*	*	12.00	31.41	36.05
Rugaragara control	*	*	*	*	*	*	*	*	11.06	13.95
Rwungo	*	*	*	*	*	*	*	*	*	18.10
Rwungo control	*	*	*	*	*	*	*	*	*	*

Appendix 5: Statistical summary of the woody species at Gishwati side

Sample	Mean Individuals	Variance	Standard Deviation	Standard Error	Total Individuals	Total Species
Corridor	4.172	75.719	8.702	1.616	121	14
Corridor control	2.483	154.259	12.42	2.306	72	4
Kinyenkada control	1.103	7.882	2.807	0.521	32	5
Kinyenkanda	1.897	16.025	4.003	0.743	55	9
Matyazo	4.034	73.034	8.546	1.587	117	16
Matyazo control	2.621	199.173	14.113	2.621	76	1
Rushubi	5.655	137.734	11.736	2.179	164	19
Rushubi control	1.966	78.463	8.858	1.645	57	2

Appendix 6: Statistical summary of the woody species at Mukura side

Sample	Mean Individuals	Variance	Standard Deviation	Standard Error	Total Individuals	Total Species
Rugaragara	2.724	10.207	3.195	0.593	79	18
Busoro2	5.414	57.68	7.595	1.41	157	18
Busoro2 control	1.276	47.207	6.871	1.276	37	1
Ndaba	2.276	7.993	2.827	0.525	66	15
Ndaba control	1.172	39.862	6.314	1.172	34	1
Rucanzogera	1.621	7.387	2.718	0.505	47	11
Rucanzogera control	0.931	25.138	5.014	0.931	27	1
Rugaragara control	1.069	33.138	5.757	1.069	31	1
Rwungo	2.138	11.623	3.409	0.633	62	14
Rwungo control	0.207	1.241	1.114	0.207	6	1

Appendix 7: Similarity Matrix of woody species at Gishwati side

	Corridor	Corridor control	Kinyenkada control	Kinyenkanda	Matyazo	Matyazo control	Rushubi	Rushubi control
Corridor	*	41.62	24.20	23.33	42.15	36.82	22.15	48.35
Corridor control	*	*	28.85	7.87	9.52	90.54	6.78	75.97
Kinyenkada control	*	*	*	41.38	29.53	20.37	10.20	44.94
Kinyenkanda	*	*	*	*	38.37	0.00	16.44	12.50
Matyazo	*	*	*	*	*	4.15	47.69	16.09
Matyazo control	*	*	*	*	*	*	4.17	70.68
Rushubi	*	*	*	*	*	*	*	6.33
Rushubi control	*	*	*	*	*	*	*	*

Appendix 8: Similarity Matrix of woody species at Mukura side

	Rugaragara	Busoro2	Busoro2 control	Ndaba	Ndaba control	Rucanzogera	Rucanzogera control	Rugaragara control	Rwungo	Rwungo control
Rugaragara	*	40.678	5.1724	59.3103	5.3097	36.5079	5.6604	5.4545	51.0638	7.0588
Busoro2	*	*	3.0928	46.6368	3.1414	34.3137	3.2609	3.1915	21.9178	3.681
Busoro2 control	*	*	*	3.8835	95.7747	26.1905	84.375	91.1765	0	27.907
Ndaba	*	*	*	*	4	49.5575	4.3011	4.1237	45.3125	5.5556
Ndaba control	*	*	*	*	*	27.1605	88.5246	95.3846	0	30
Rucanzogera	*	*	*	*	*	*	29.7297	28.2051	25.6881	22.6415
Rucanzogera control	*	*	*	*	*	*	*	93.1034	0	36.3636
rugaragara control	*	*	*	*	*	*	*	*	0	32.4324
Rwungo	*	*	*	*	*	*	*	*	*	0
Rwungo control	*	*	*	*	*	*	*	*	*	*

Appendix 9: Native herbs species abundance at Gishwati side

Comparison of herbs species identified in the Eucalyptusremoved area with the control at Gishwati side									
Species	**Corridor**	**Corridor control**	**Kinyenkada control**	**Kinyenkanda**	**Matyazo**	**Matyazo control**	**Rushubi**	**Rushubi control**	**Grand Total**
Alchemilla johnstonii	0	0	4	0	0	23	0	8	35
Alectra sessiliflora	7	0	0	4	13	0	0	0	24
Asplenium friesiorum		0	0	0	0	0	1	0	1
Asplenium kuhnianum	15	0	0	0	0	0	0	0	15
Canarina eminii	10	0	0	0	0	0	0	0	10
clematis simensis	0	0	0	0	1	0	0	0	1
Coelachne africana	75	9	8	77	199	14	66	16	464
Crassophorum vitellinum	3	0	0	0	0	0	0	0	3
Cyanotis barabata	17	4	0	5	0	0	1	3	30
Drymaria cordata	7	0	0	0	0	2	6	0	15
Helichrysum foetidum	2	0	0	0	0	0	0	0	2
Helichrysum helvolum	4	0	0	0	0	0	0	0	4
Hydrocotyle mannii	0	0	0	0	0	14	0	0	14
Impatiens burtonii	0	0	0	0	0	0	3	0	3
Impatiens gesneroidea	0	0	0	0	0	0	5	0	5
Impatiens kagamei	0	0	0	0	0	0	5	0	5
Impatiens niamniamensis	0	0	0	0	0	0	12	0	12
Ipomea involucrata	12	0	0	11	19	0	11	0	53
Isachne mauritiana	0	0	10	0	0	28	0	0	38
Kyllinga stenophylla	0	8	31	0	5	0	40	0	84
lobelia gibberoa	0	1	0	0	0	0	0	0	1

Lotus becquetii	0	15	0	0	0	0	0	0	15
lycopodiella cernua	2	0	0	0	0	0	0	0	2
lycopodiella clavatum	60	0	0	0	0	0	0	0	60
lycopodium clavatum	45	0	0	42	0	0	0	0	87
Mariscus tomaiophyllus	0	0	0		0	0	0	3	3
Otiofora pauciflora	0	0	0	62	0	0	0	0	62
Otiophola pauciflora	0	0	2	0	0	0	0	0	2
Pennistum clandestinum	0	0	5	0	0	26	0	23	54
Phyllanthus nummulariifolius	15	3	19	0	40	9	34	0	120
Plantago palmata	0	0	0	0	0	4	0	5	9
Plectranthus serrulatus	0	0	0	0	3	0	0	0	3
Pneumatopteris afra	0	0	0	0	14	0	0	0	14
Pteridium aquilinum	4	3	4	14	18	1	4	1	49
Rubus steudneri	5	0	0	0	3	0	5	0	13
Rumex abyssinicus	1	0	0	0	0	0	0	0	1
Scleria distans		0	0	0	32	0	0	0	32
Senecio maranguensis	5	0	0	22	0	0	3	0	30
Senecio subsessilis	0	0	0	0	1	0		0	1
Solenostemon sylvaticum	0	0	0	0	0	0	9	0	9
Spermacoce princea	5	11	0	15	27	2	16	5	81
Grand Total	**294**	**54**	**83**	**252**	**375**	**123**	**221**	**64**	**1466**
Abundance of the species in the E. removed area	1142								
Abundance of the species in the controls	324								

Abundance of the species in the E. removed area per $1m^2$	57
Abundance of the species in the non-E. removed area	16

Appendic:10. ***Native herbs species abundance at Mukura side***

species	Busoro 2	Busoro 2 control	Ndaba	Ndaba control	Rucanzogera	Rucanzogera control	Rugaragara	Rugaragara control	Rwungo	Rwungo control	Total
A splenium friesiorum	3	0	0	0	0	0	0	0	0	0	3
Alchemilla ellenbeckii	8	0	0	0	0	0	0	0	2	0	10
Alchemilla johnstonii	0	0	4	4	6	3	0	2	0	0	19
Alectra sessiliflora	2	0	16	0	0	0	1	0	3	0	22
asplenium kuhnianum	0	0		0	0	0	4	0	0	0	4
botrioclyne longipes	12	0	6	0	0	0	0	0	0	0	18
brillanthaisia nitens	10	0	0	0	0	0	6	0	0	0	16
Carex conferta	0	0	0	0	0	0	0	0	3	0	3
Coelachne africana	18	28	18	0	18	13	29	0	15	6	145
Conyza welwitschii	0	0	0	0	0	0	0	0	2	0	2
Crassophorum paludum	0	0	0	0	0	0	0	0	3	0	3
cyanotis barabata	13	2	0	0	0	0	0	0	2	0	17
Digitaria abyssinica	0	0	0	0	0	0	0	0	15	0	15
drymaria cordata	25	0	19	0	3	0	4	0	0	0	51
Epilobium salignum	0	0	0	8	0	3	0	2	0	0	13
Helichrysum globosum	3	0	0	0	0	0	0	0	0	0	3
hypericum scioanum	15	0	0	0	0	0	0	0	15	0	30
impatiens burtonii	21	0	0	0	0	0	6	0	0	0	27
Ipomea involucrata	7	0	2	0	3	0	6	0	7	0	25

isachne mauritiana	0	0	0	0	0	0	0	0	0	8	8
Isodon ramosissimus	21	0	0	0	15	0	0	0	0	0	36
kyllinga appendiculata	0	0	0	0	0	0	0	0	3	0	3
kyllinga stenophylla	14	0	4	2	6	6	6	4	5	11	58
lindernia nummulariifolia	8	0	0	0	0	0	0	0	10	0	18
lobelia molleri	0	0	0	0	0	0	0	0	19	0	19
mimulopsis excellens	3	0	0	0	0	0	0	0	0	0	3
otiophora pauciflora	0	0	0	0	0	3	0	0	0	0	3
Panicum eickii	0	0	0	0	0	0	0	0	3	0	3
paspalum scrobiculatum	0	0	0	9	9	4	0	13	33	0	68
pennistum clandestinum	3	2	0	0	4	0	0	0	0	0	9
Phyllanthus nummulariifolius	31	2	17	0	20	0	28	2	28	2	130
Plantago palmata	2	0	0	0		0	0	0	0	0	2
plectranthus serrulatus	0	0	0	0	3	0	0	0	14	0	17
Pteridium aquilinum	3	10	0	0	0	0	7	0	0	2	22
pycreus nigricans	0	0	0	0	0	0	0	0	56	0	56
Rubus steudneri	0	3	0	0	0	0	0	0		0	3
Senecio maranguensis	6	0	10	0	8	0	4	0	24	6	58
Spermacoce princea	17	7	7	2	8	0	6	3	18	0	68
swertia usambarensis	14	0	0	0	0	0	0	0	16	0	30
Torenia thouarsii	0	10	27	5	0	7	0	6		0	55
vigna parkeri	0	0	3	0	0	0	0	0	4	0	7
Virectaria major	12	8	19	0	9	0	11	0	66	19	94
Grand Total	**271**	**72**	**152**	**30**	**112**	**39**	**118**	**32**	**366**	**54**	**1246**
Abundance of the species in the controls	227										
Abundance of the species in the E. removed area per $1m^2$	60										
Abundance of the species in the non E. removed area per $1m^2$	13										

DECLARATION

I, Fulgence HAGUMUBUZIMA, declare that this dissertation titled "assessment of impacts of removing *Eucalyptus* species on natural regeneration of native species at Gishwati-Mukura National Park" is the result of my own work and has not been submitted for any other degree at the University of Rwanda or any other institution.

Declaration on the use of the anti-plagiarism checker.

Printed Name: Fulgence HAGUMUBUZIMA

Signature:

Declaration from the Main Supervisor that he is approving submission of the dissertation for examination.

Prof. NSABIMANA Donat

Signature:

DEDICATION

This dissertation is dedicated to:

All might of God

My beloved family,

My parents

My brothers and sisters,

My supervisors,

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I am grateful to the almighty of God who protected me during all my study.

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May God bless you all!

Abstract

The aim of this research was to assess the impacts of removing the *Eucalyptus* species on the natural regeneration of native species at Gishwati-Mukura National Park. The eighteen study sites were selected from the *Eucalyptus* species removed and non-removed areas, with three and five randomized plots in each site of Mukura and Gishwati sides respectively to identify the native and non-native plant species regenerated, the number of E. stumps regenerated, and E. seedlings germinated. A quadrat of $1m^2$ was used for the herbs species identification, $25m^2$ and $100m^2$ for the identification of the woody species (shrubs and trees) having less than 2m and greater or equal to 2cm of diameter at breast height correspondently. A straight line of 100m long from the edge of the buffer zone was drawn in and out the Park to identify the distribution potential of *Alnus* inside and outside of the Park. A quadrat of $1m^2$used for quantification of the number of *Alnus* seeds and seedlings germinated at 0, 5, 15, 30, 50, 75 and 100m distances. The plants species abundance, diversity indices, evenness and the coppiced stumps abundance were analyzed with the Excel sheet, pivot table and bioproffessional software.

The total of 20 *Eucalyptus* stumps were coppiced among 197 E. stumps counted in the whole study area and 3 E. seedlings were identified. The estimated number of herbs species were highly abundant at E. removed area at 60 herbs species compare to 13 herbs species in non-E. removed areas per $1m^2$at Mukura side. Gishwati side was 57 herbs species in E. removed area compare to 16 herbs species in non E. removed area per $1m^2$with high dominance of the *Coelachne africana, Phyllanthus nummulariifolius* herbs in both study sides. The areas were highly dominated by the pioneer woody species such as *Macaranga kilimandscharica, Maesa lanceolata, Dombeya torida, Bothriocline ruwenzoriensi*, *Xymalos monospora,* and low abundance of climax species like *Carapa grandiflora*, *Podocarpus falcatus, Syzygium guinens* in the whole study area. The results shown that the E. species had numerous influence on the native species regeneration by competing with native species, the E. leaves litter and chemical substances inhibiting the regeneration of native species in the nature area.

Key words: Biodiversity; plant species diversity; abundance; Gishwati, Mukura national Park; *Euclyptus*; *Alnus*; regeneration

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List of abbreviations

ANR: Accelerated Natural Regeneration

CAVM: Colle of Agriculture, Animal science and Veterinary Medicine

DBH: Diameter at Breast Height

GPS: Global Position System

H’: Shannon diversity index

J: Evenness index

LAFREC: Landscape Approach to Forest Restoration and Conservation

REMA: Rwanda Environmental Management Authority

UR: University of Rwanda

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CHAPTER 1. INTRODUCTION

The *Eucalyptus* species originated in Australia and was introduced elsewhere for its fast growth, timber and energy production (Tang et al., 2007; Zhao et al., 2007). It is easily established with high growth performance and high production, however the *Eucalyptus* species become invasive to its surround natural plantation (Calvino-cancela et al., 2013). This resulted to the loss of biodiversity in the understory and degrading the soil. Hua-Feng Wang et al. (2011)have shown the reduction of biodiversity in the *Eucalyptus* plantation which was a critical issue for the long term of native ecosystem.

In China, different varieties of *Eucalyptus* were introduced and presented the high proliferation in the country and caused a high decrease of biodiversity due to its chemical substances contained by E. leaves (Chu et al., 2014).

In Florida, different plant species planted, 30% is made of the exotic species (non- native species) which were established from other countries or region and became invasive in the area with the high growth and spreads, this caused the loss of habitant for native species (bird, plant and other wild animal) and the reduction of biodiversity (Demers et. al., 2016). According to Milestones (2010), among the harmed exotic species to the native species includes plant *Eucalyptus* species which inhibit natural processes and the continuance of natural features of native species and there is a need for the management of exotic species for the protection of the park's natural and cultural resources from the impacts of the exotic species.

The study conducted at Sierra Nevada exposed that the most exotic species found in the natural ecosystem were introduced either by human activity, transport, and or environment modification and provide opportunities to be established in natural area. The introduced exotic species were harmful to the native species by extinction of native species and destruction of biological diversity and decrease the population of native species (Dyer, 1996).The humans' activities contributed significantly in spreading the exotic plant species in the ecosystem and become abundant in human- influenced ecosystems(Knops et al., 2014).

The Gishwati Forest Reserve, a hundred years ago, was a secondary mountain rain forest with the largest number of indigenous species in Rwanda and covered approximately 100,000 hectares. In 1970, the area was reduced to a fourth of the total size to 28,000 hectares; due to cattle ranching (39.6%), human settlement and small farms (38.6%) and planted Pine and *Eucalyptus* woodland (12.5%) (Kisioh, 2018).

In 1980, 70% of the total area of the Gishwati natural forest was converted into pasture land and *Eucalyptus* species plantation alongside cattle ranching (Kisioh, 2018). After the 1994 Genocide, refugees resettled in Gishwati-Mukura natural forest which resulted in the clearing of native forest for agriculture and establishment of non-native species including *Eucalyptus spp* and *Acacia meansis* (Kisioh, 2018).

Thereafter the communities surrounding the Gishwati-Mukura landscape continued to enter inside the forest to cut down trees (both native and non-native trees species) for timber, rope, stick, bamboo and medicinal plants collection to satisfy their needs (Kisioh, 2018).

Large areas within the Gishwati-Mukura landscape have been threatened by the established exotic species (*Eucalyptus* sp, *Acacia meansis* and *Acacia melanoxylon*) (Richardson et al, 2006). The exotic species occupied the natural area and have the capacity to be established themselves in natural area and compete the native species, kill and displaced them in the native habitant (Kisioh, 2018).

The exotic seeds dispersal in the natural area contribute to forest dynamics. The success of seeds dispersal is subject to the amount of seeds dispersed, the viability and kind of treatment provided by seed dispersers. (Isabel & Pinto, 2018). According to Bullock & Clarke (2000) invasive species seeds can be dispersed and be invaders if they reached in the appropriate environment. Many seeds have dispersed in the short distance and the few seeds reach longer by human intervention. The dispersal of exotic species varies with the seeds and the host environment. The *Alnus* species is originated from Mexico, was planted along side of Gishwati as the buffer zone to delimit the movement of people entering in the park and reduce the level of the encroachment. The *Alnus* species have small seed which can be dispersed by wind for the long distance and by gravity for short distance. The number of *Alnus* species seeds in one kilogram is more than 2 million pure seeds which can germinate at 50-70% in the good condition (Orwa C et al., 2009). The *Alnus* species have shading effect and degrading nature habitat. The species forms monospecific stands that out-compete native species to the water, nutrients and sunlight (Anderson and Hayley, 2013). The spread of exotic species varies with its invasiveness and community invasibility (Calviño-cancela & Rubido-bará, 2013).

1.1. Problem statement

The degradation of the Gishwati-Mukura landscape is a result of over-exploitation of natural resources through agricultural, livestock and mining activities which have consequently resulted in the loss of biodiversity, including indigenous plant species, wild animals, birds, ecological integrity and ecosystem functions (services and products) as well as the increase of exotic species in the landscape (Kisioh, 2018). The *Eucalyptus* species is one of the established exotic tree species in the park, which have high competition to the native plant species in term of light, soil water and nutrients leading to its high growth in the ecosystem and totally displaced native species from their native habitat through diseases to which they have not developed resistance, outcompete them as well as alteration of ecological functions (Heras et al., 2013) and change the microbial community structure and function in the soil (Kourtev et al., 2015). The impact assessment of removing the *Eucalyptus* species on the nature regeneration has never been studied at Gishwati-Mukura National park. Therefore, this research is very crucial, because the native species regenerated in the area will provide the information on how the ecological functionality and environmental balance will be after the removal of *Eucalyptus* species. The aim of this research was to assess the effect of removing *Eucalyptus* species on natural regeneration of native species in the Gishwati-Mukura National Park. The specific objectives were: (i) to evaluate the number of *Eucalyptus* stumps coppiced and *Eucalyptus* seedlings germinated in the study area; (ii) to compare the native and non-native species abundance, and diversity in the E. removal and non-E. removal sites; (iii) to assess the regeneration potential of *Alnus* species used as buffer zone in and out of the Gishwati side. The present study proposed the research questions related to the specific objectives:(i) what are the *Eucalyptus* stumps that are coppiced and E. seedlings germinated after their removal? ;(ii) what native and no-native species return post-*Eucalyptus* species removal, and what is their abundance and diversity indices on the removal sites within the study areas compared to non- E. removal sampled sites? (iii) what are the regeneration potential of *Alnus* species used as buffer zone in and out the Gishwati side?

CHAPTER 2. LITERATURE REVIEW

The deforestation, mining and invasion of exotic species (*Eucalyptus* sp, *Acacia melanoxylon, Acacia mearnsii* etc) at Gishwati and Mukura Forests led to land cover change and subsequently to landscape degradation and environmental deterioration (Mukashema, 2007). The forest of Gishwati, initially estimated to be 280 km^2 was reduced to only 7 km^2, which constitute a loss of 80 % of initial natural forest cover (Mukashema, 2007). This was accompanied with the loss of the chimpanze (*Pam Troglodytes*) and Golden Monkey (*Cercophithecus mitis Kandti*), as well as a number of bird species and indigenous tree species (Official et al., 2014).

The remaining Natural Forest Landscape supports an isolated population including chimpanzees (*Pan troglodytes*), thought to number between 19 and 29, golden monkeys (*Cercopithecus mitis kandti)* and L'Hoest's monkeys (*Cercopithecus lhoesti)* and more than 130 species of birds in Gishwati (Chancellor et al., 2012). In 1951, Mukura Forest Reserve was established with a total area of 2,000 hectares, but has now been reduced by encroachment of agriculture to about 1,200 hectares. The remaining patch of Mukura Forest hosts an interesting biodiversity, including a total of 243 plant species (Rwanda, 2011).

The baseline survey on the biodiversity carried out at Gishwati-Mukura National park has shown that the most abundant tree species in the park such as *Macaranga* , *Polyscias fulva, Symphonia globulifera, Carapa grandiflora and Syzygium guineense*, *Maesa lanceolata* and *Dombeya torrida* were identified in the two forests(Park, 2018). The common grass fodder species identified included *Isachne mauritiana* and *Coelachyne African*. The *Ipomoea involucrate, Embelia schimperi* were identified as the climbers. There was high diversity of *Drymaria cordata*, Impatiens species and *Asplenium friesiorum* herbs species. In the open disturbed area *Pteridium aquilinum*, *Vernonia spp* were highly abundant. The woody understory species such as *Mimulopsis arborescens, Mimulopsis solmsii, Mimulopsis excellens, Allophyllus chaunostachys , Clutia abyssinica*, were present.

The gramineous herbs species were highly occupied in the degraded zone. In the fertile soil, there was high presence of *Mimulopsis, Justicia* and hypoestes species. The *Triumfetta cordifolia* created a monospecific community and covering large area in the forest(Park, 2018). The family of Rubiaceae, like Pavetta, Galiniera species were observed in the understory of the

tall tree in the two forests. There was the occurrence of the secondary forest species such as *Macaranga capensis var. kilimandscharica and Maesa lanceolatae*, (non- shade tolerant species) once they made a closed canopy can allow the germination of shade tolerant species.
Macaranga capensis and *Maesa lanceolata* community: a typical secondary forest was identified in severely-disturbed areas of Mukura and Kinyenkanda section of Gishwati. The two tree species dominant in the community are known to grow only after primary forest clearing. They clearly indicate former severe disturbance but they also provide hope of accelerated forest regeneration. The presence of rare species like *Salacia erecta* and *Afrocrania volkensii* is also characteristic of this community demonstrating a potentially recovering forest (Report & Consultancy, 2017)

The research conducted at North America, where the exotic shrubs species removed to the native species regeneration proven that after post exotic species removal, there was more dense understory of native species and increased biodiversity regrown in the removal area (Maynard-bean et. al.,2019). The native species regenerated were categorized into herbs, shrubs, trees and climbers with the high abundance of herbs species (Maynard-bean et al., 2019). In Southern Western India, a study has proved that on the cleared *Eucalyptus* forest resulted the high abundance of native species regenerated with different states (adults, saplings and seedlings) brought by winds, animal and birds compare to the mature *Eucalyptus* plantation aged at 25 years (Selwyn & Ganesan, 2009).
In China, it was observed that under some *Eucalyptus and Pinus* species, the natural regeneration is inhibited due to allelopathy, allelochemical volatilization and foliage litter (Chu et al., 2014). The regeneration of native saplings under plantation seemed to vary depending on the species of over-story of exotic trees. For instance, some exotic over-story trees like *Casuarina equisetifolia* may inhibit the regeneration of native saplings (Loo et al., 2017).
Assisted natural regeneration was done in Nyungwe National Park in the burnt areas by cutting the fens (*Pteridium aquilinum*) in 2007 within plot to allow light to reach the ground, and the results showed that in the first years, new seedlings have appeared included *Macaranga kilimandscharica*, *Polyscias fulva* at Kitabi, Umugote, Gasare, and Mubuga plots site (Park N.N., 2007).

In Uganda, the logging of *Cypress* and *Eucalyptus* exotic species for the regeneration of indigenous species resulted the high regeneration of values species richness in a pit sawn area of *Cypress* and *Eucalyptus* at 75 and 55 than in unlogged plantations respectively (Kasenene, 2007). The intervention from LAFREC project removed the *Eucalyptus* species and assisted natural regeneration in the Gishwati-Mukura National Park on an estimated total area of 484 ha. The assisted natural regeneration method is referred to as Accelerated Natural Regeneration (ANR) which is a potentially rapid, efficient and cost effective means to reforest critical areas.

It involved planting of seedlings produced in a nursery, high germination cuttings in the removal site (Shono, Cadaweng, & Durst, 2007). ANR is a method for enhancing the establishment of secondary forest from degraded areas by protecting and nurturing the mother trees and their wildlings inherently present in the area. The native species that were used to regenerate the Gishwati Forest include *Polysias fulva, Podocarpus falcatus, Carapa grandiflora, Syzigium guineense, Parinari exselsa,* and *Croton macrostachyus*. The *Eucalyptus* species removal enhanced the natural regeneration of native species and improve the sun light to reach on the understory and ground, where the dormant native seeds can germinate (Karen & David, 2011).

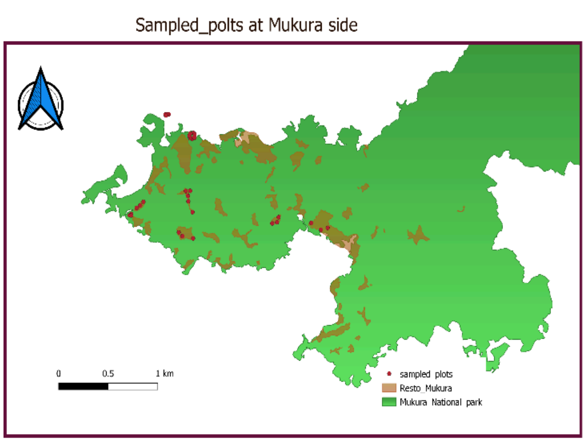
The seeds fallen on the ground receive the favorable conditions (light, moisture and growing medium) enabling seeds to germinated. The natural regeneration is important in the natural reserve management and it is a fundamental in the evolution of forest ecosystem. (Jónsson, 2016). The removal of *Eucalyptus* species in the Gishwati-Mukura National Park was done by cutting down trees, debark, remove the coppices and remove the E. stumps in some area of Mukura side to avoid the occurrence of the E. in the parks (Tuyishime, 2017). This research availed the data on number and what shade and non-shade tolerant species regenerated at post *Eucalyptus* species removal, species abundance and richness to the site to ensure functioning of the ecological services and products provision as an economic engine for the surrounding communities and fully community involvement in the protection of the park.

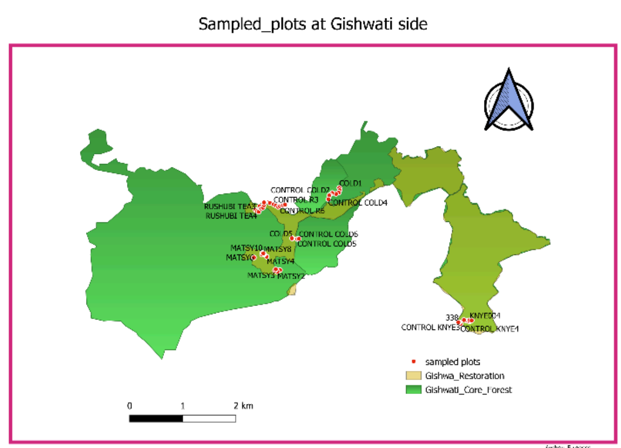
In addition, this provided the data of native and non-native species regenerated in Gishwati-Mukura National Park study sites to help the park management authority to take any other conservation measures to fully functioning of the park.

CHAPTER 3.MATERIALS AND METHODS

3.1. Study area location and characterization

The Gishwati-Mukura National Park is situated in north-west of Rwanda, between 29^{o}21’40’’ – 29°28’5’’ East and between 1°36’52” – 1°52’17’’ South with altitude ranging from 2000m to 3000m above sea level. The landscape has an averaged cool temperature of 10°C and mean annual rainfall of 1800 mm (Nyandwi & Mukashema, 2011). The umbrisol soil type of Gishwati-Mukura landscape formed from the decomposition of organic matter which enrich the soil in terms of soil nutrients (Kisioh, 2018). Mukura and Gishwati touch 4 districts, Rutsiro and Rubavu districts in west and Ngororero and Nyabihu districts in east (Nyandwi & Mukashema, 2011). Mukura is located within Rutsiro and Ngororero Districts. Much as these reserves are now detached, history shows that Mukura forest used to be attached to Gishwati and Nyungwe before agents of deforestation came (Tharcisse, 2014). Gishwati-Mukura landscape is bounded by cropland and the grazing areas and crossed by Pfunda River (Tharcisse, 2014). The research was conducted where the *Eucalyptus* tree species were removed by LAFREC project inside the park as shown on the maps below.





3.2. Dominant vegetation

A recent study of carbon sequestration of the forest indicated that *Macaranga kilimandscharica (*umusekera*)* is the most common tree species in Gishwati –Mukura National Park. Previously disturbed regions of the forest experiencing regeneration show colonization of

Carapa grandiflora (Umushwati), *Entandrophragma excelsum* (umuyove) and *Symphonia globulifera*. Other floras of the reserve include giant tree ferns and blue lichen (Kisioh, 2018). The assisted regeneration made composed by *Neoboutonia macrocalyx* and *Polyscias fulva*. Mukura Forest contains highly diversified and rich flora. Among its flora at least 243 plant species, the following are predominant: *Psychotria mahonii, Macaranga, Psydrax parviflora, Syzygium guineense, Rytiginia kigeziensis, Mutundu, Rapanea melanophroides,* lemonwood, *Peddiea rapaneoides, Galiniera saxifraga, Vernonia lasiopsis, Chassalia subchreata, Hagenia*, false assegai, *Olinia rochitiana, chewstick, lebekyet*, silky bark and *Vernonia kirungae*(Park, 2018).

3.3. Sampling design

Eucalyptus species was removed in Gishwati-Mukura National Park in 2015, where 63ha was in patches both in Gishwati and Mukura Landscape (Tuyishime, 2017). A purposive sampling method used to locate the *Eucalyptus* species removed and non-*Eucalyptus* removed areas. Thereafter, simple random sampling method used to locate the plots where each plot had equal probability of being selected to represent the population. The *Eucalyptus* species removed areas were identified together with the local peoples and randomization of 10m grid was done with Quantum Gis software.

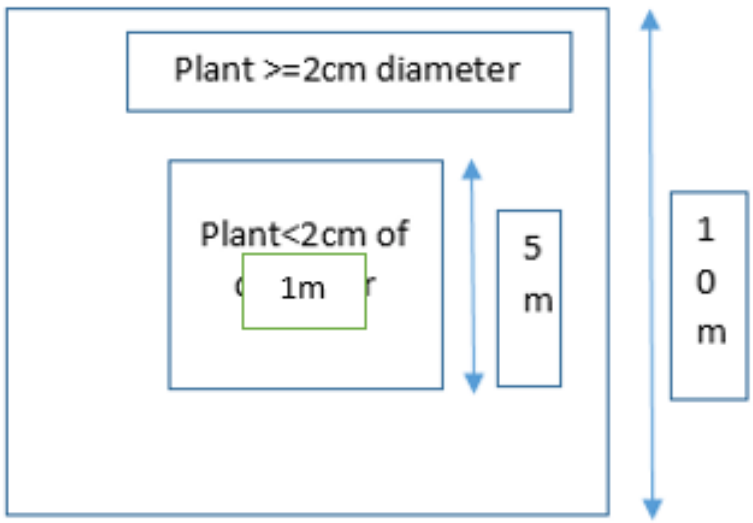
Sampling unit center was tracked with Global Position System (GPS) receiver after entering the geographical coordinates (longitude and latitude) in the GPS to define plot size of 10mx10m.

In the quadrat plots of 10mx10m exotic and native tree species having >= 2cm of Diameter at Breast Height (DBH) regrown was identified, counted and recorded on the field form.

In the big plot, a small quadrat plot of 5mx5m was for the counting and identifying exotic and natives plant species having DBH < 2cm regenerated in the study areas and for the herb layer data collected within

1mx1m. The controls were at non- *Eucalyptus* removed sites for each sample size (i.e. 10x10m, 5mx5m and 1mx1m).

Experiment design in the study areas



From the *Alnus* buffer 100m was measured from the edge toward outside and inside of the Park. The seeds and seedlings of *Alnus* species were collected at 0, 5, 15, 30, 50, 75 and 100m distance within quadrat of 1m in the study areas. A line had 7 quadrat plots which was replicated in 4 sampling areas(Vespa etal., 2018)

3.4. Sample size

The sample sites of *Eucalyptus* species removed area and no removal area of Kinyenkanda, Matyazo, Rushubi and Corridor of Gishwati side and Busoro, Rwungo, Rugaragara, Ndaba and Rucanzogera of Mukura side together with their control made 18 sampling sites which were used during the data collection. In each sampling site, we randomized 3 and 5 sampling plots at Mukura and Gishwati sides respectively. The total number of 74 sampling plots were randomized in 18 sampling sites during data collection.

3.5. Data collection

The species names (scientific and vernacular) were identified whether the plant species is native or exotic by using Fischer & Killmann (2008) and the Plant List Database.

Number of stems present on the study sites which help us to know the species density, richness and evenness and the life form of plant species to differentiate the tree, shrubs and herbs species regenerated after exotic species removal were collected within 10mx10m, 5mx5m and 1mx1m plot sizes.

3.6. Data analysis

The shade and no shade tolerant tree species, herbs species abundance, Shannon diversity index (H') and evenness index (J) in the study areas (*Eucalyptus* species removed and control) were analyzed in the excel sheet with pivot table and bio professional software. The comparative graphs of E. stumps coppiced, E. seedlings, number of *Alnus* seeds and *Alnus* seedlings were analyzed with excel sheet.

CHAPTER 4. RESULTS

4.1. The number of *Eucalyptus* stumps, E. stumps coppiced and *Eucalyptus* seedlings

The 17 plots in the *Eucalyptus* removed area of Mukura side, a total number of 81 *Eucalyptus* stumps counted, 8 *Eucalyptus* stumps were coppiced (Fig.1). The high number of E. stumps coppiced were located at Busoro2 compare to Rugaragara and Rwungo sites which had none E. coppiced stumps.

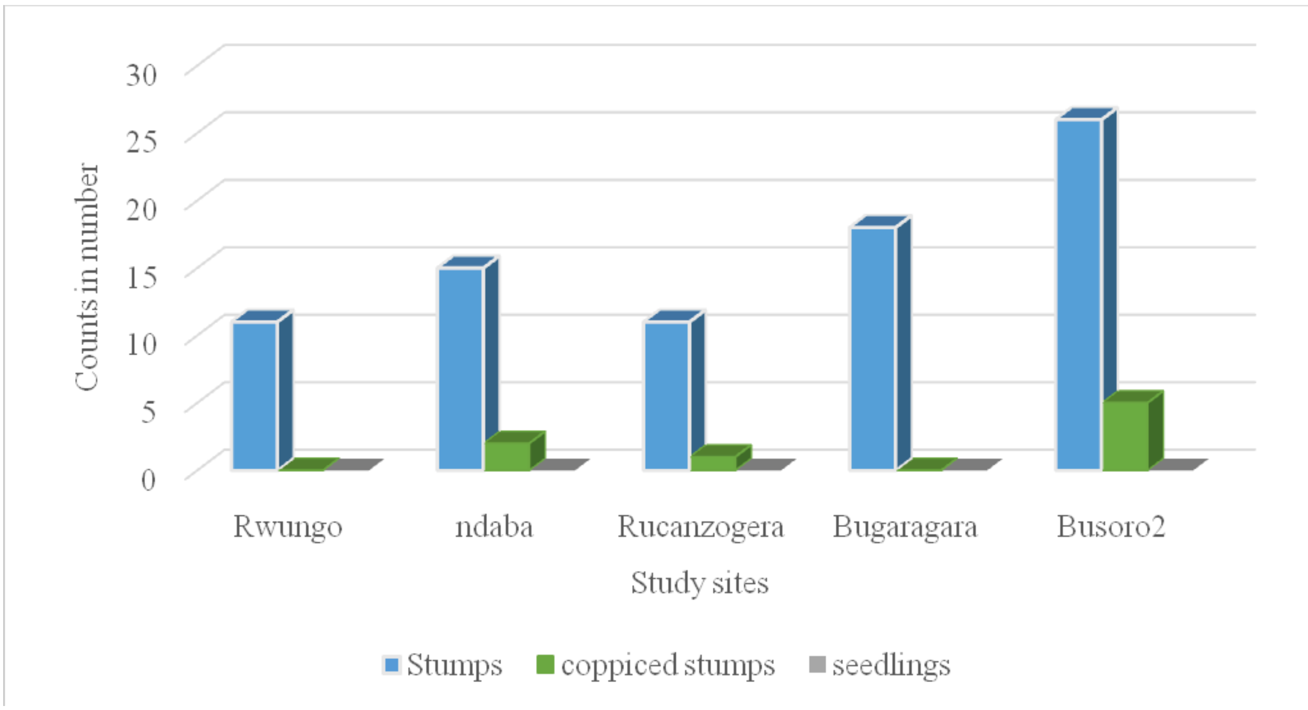


Figure 1: The number of *Eucalyptus* stumps, E. stumps coppiced and *Eucalyptus* seedlings counts at Mukura side.

The number of E. stumps, E. stumps coppiced and E. seedlings were recorded within 25 m^2 (quadrat of 5mx5m) at Rwungo, Ndaba, Rucanzogera, Rugaragara and Busoro2 sites. The were no E. seedlings germinated in the area.

The 4 study sites of Gishwati include Matyazo, Rushubi, Corridor and Kinyenkanda sites, a total number of 116 *Eucalyptus* stumps with 12 E. stumps coppiced were identified. This was due to the improper stump debarking done on some stumps. Only 3 E. seedlings germinated in the whole study sites of Gishwati were recorded **(**Fig.2**)**. The high number of E. stumps coppiced were recorded at Rushubi and Matyazo at 6 and 5 stumps coppiced respectively compare to Kinyenkanda which had none E. stumps coppiced.

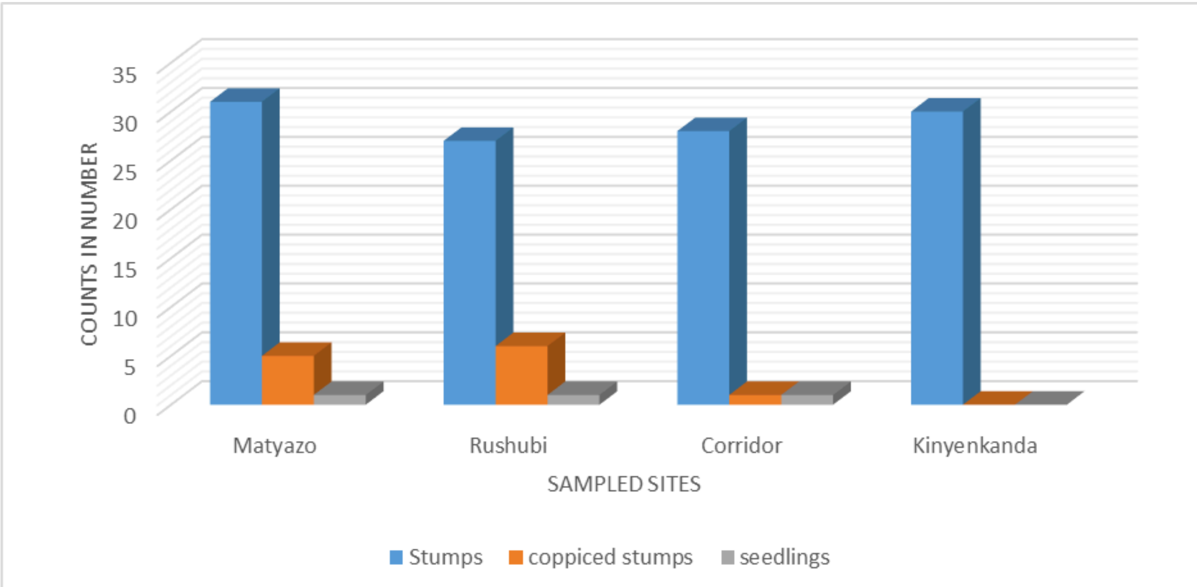


Figure 2: The number of E. stumps, E. stumps coppiced and E. seedlings counts at Gishwati side

The number of E. stumps coppiced was low due to the debarking and the stumps management activities done after the tree cutting, except at Rushubi and Matyazo sites some stumps were not debarked and did not receive any stumps management activity which caused a number of 6 and 5 stumps coppiced respectively.

4.2. Regeneration potential of *Alnus* species inside and outside of the Gishwati side.

A portion of Gishwati buffer zone is made by *Alnus* species. The *Alnus* tree seeds movement inside and outside of the Park were driven by different factors. The total estimated number of *Alnus* seeds was 606 at both inside and outside of the Park with the high number of seeds at 0 and 5 m distance while at 100m distance there was no seed (Fig 3). A total of 77 *Alnus* seedlings were counted outside the parks in pasture land and none seedlings inside the park (Fig. 4).

The number of seeds distributed alongside of the line decreased as the distance increased.

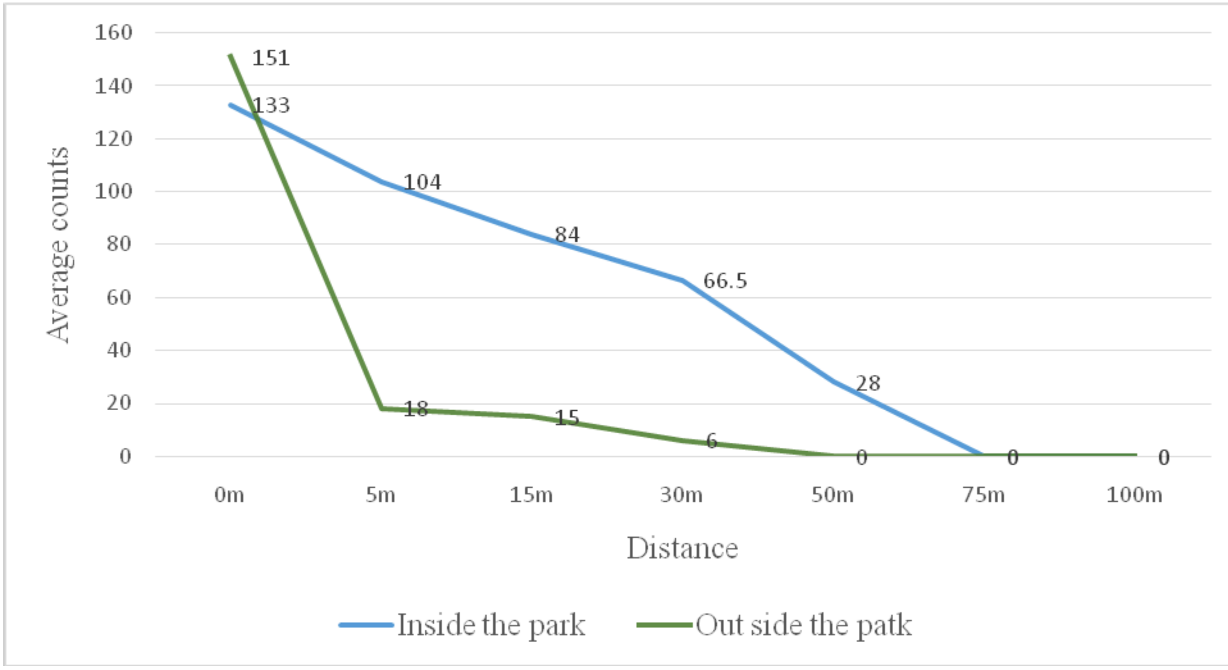


Figure 3:The *Alnus* seeds distribution inside and outside of the Gishwati

The number of *Alnus* seeds decrease as you go far from the *Alnus* tree stump.

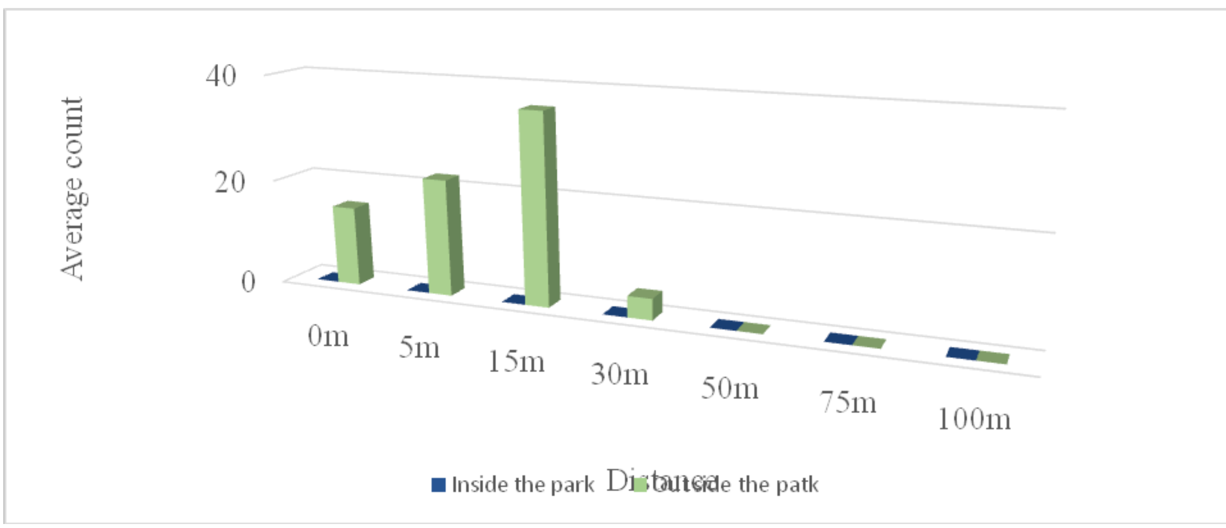


Figure 4: Abundance of *Alnus* seedlings germinated inside and outside of Parks.

The number *Alnus* seedlings increased within the first 15 meters and decrease to the zero from 50 m and above in the outside of the park due to the favorable condition that seeds reached after falling while inside the park the germination condition of *Alnus* seeds did not favor the seeds to germinate, where there was none seedling counted inside the park.

4.3. Abundance of native herbs species in the *Eucalyptus* removed and none removed areas.

4.3.1. Native herbs species in the study area

The total number of 1466 and 1246 herbs species were identified at Gishwati and Mukura sides respectively. The highest number of herb species were collected at Matyazo and the lowest at Corridor control of Gishwati side. At the Mukura side, the high abundance of herbs species recorded at Rwungo and low number at Ndaba control. The *Coelachne africana and Phyllanthus nummulariifolius* were mostly dominant herb species in both sides (Appendix 9 and 10).

4.3.2. The abundance of native and non-native woody species in the study area

The total number of woody species (shrubs and tree) identified was 380 native and 76 exotic woody species at Gishwati side. Among the exotic woody species identified, the *Eucalyptus* was dominant because it was recorded in the controls and few number in the E. removed sites. The *Macarananga kilimandscharica* dominated other native woody species as it is the first growth species in the disturbed area (Park N.N., 2007)(Fig.5).

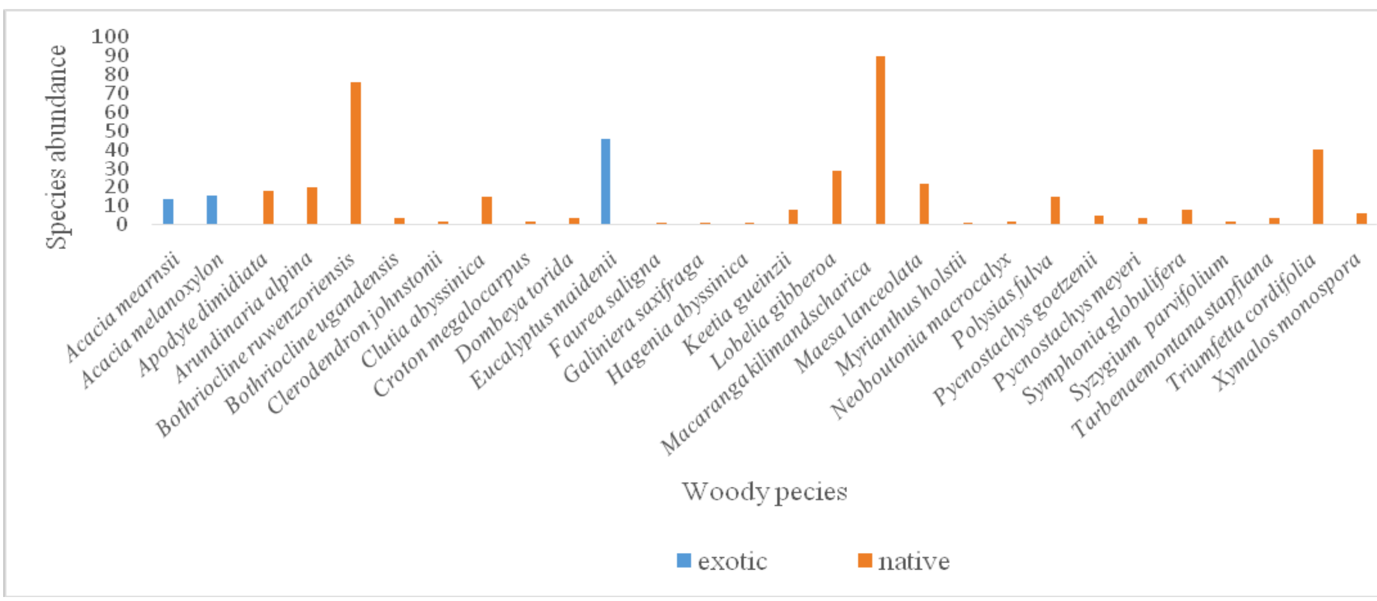


Figure 5: Comparison of the native and non-native woody species at Gishwati side

The non-shade tolerant species identified were conquered by *Macaranga kilimandscharica, Maesa lanceolata, Bothriocline ruwenzoriensis,* compared to shade tolerant species like *Symphonia globulifera*, *Syzygium guiness,* and *Hagenia abyssinica.* Some shade and non-shade tolerant woody species recorded were planted during assisted natural regeneration to quick recovery of the degraded area.

At Mukura, a total number of 378 native woody species and 33 non-native woody species of 29 different species were identified. The side was highly dominated by *Triumfetta cordifoli* (umusarenda) native woody species which is distributed in cleared area (Fischer & Killmann, 2008), and *Eucalyptus maidenii* non-native species. The area had the mature *Grevillea robusta* and *Cuppressus lusithanica* (Fig.6).

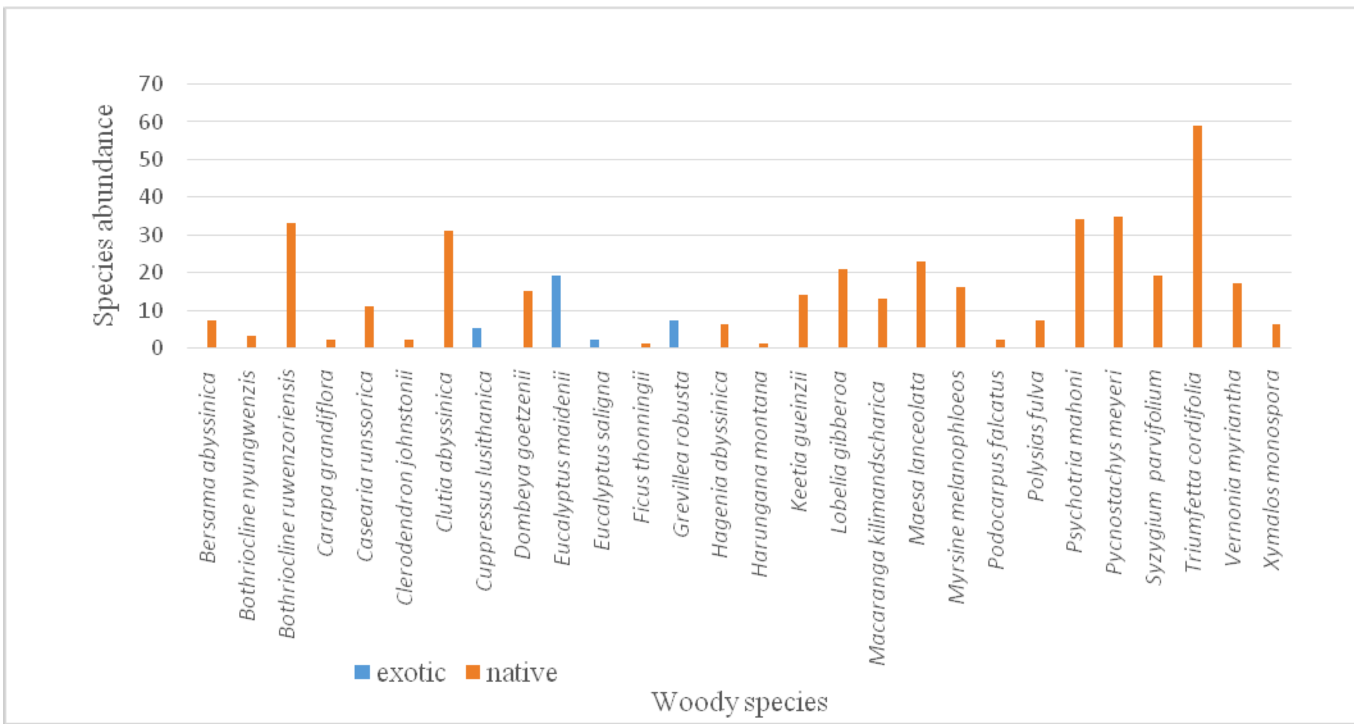


Figure 6: Comparison between native and non-native woody species at Mukura side

The secondary forest, non-shade tolerant species such as *Maesa lanceolata*, *Macaranga kilimandscharica,* were observed at the low rate compared to *Pycnostachys meyerie* and *Bothriocline* species. The shade tolerant species was identified with high dominance of *Syzygium guinenensis ssp. parvifolium* (Fig.6).

4.3.3 Diversity index and similarities of plant species in the Gishwati-Mukura National Park

At Gishwati side, the Shannon diversity for the herbs species was higher in the Corridor site while the Matyazo sites was small (Table 1). In the study sites of Mukura side, Shannon diversity was high at Busoro2, followed by Rwungo and the smallest was observed at Ndaba control (Table 2). At Gishwati, the highest similarity of the herbs species abundance was observed amongst Rushubi control and Matyazo control (55.62%) followed by the similarity between Corridor and Kinyenkanda (55.31%) (Fig.7; Appendix3). At the Mukura side, the highest similarity was observed between Rugaragara control and Ndaba control (70.97%) and the similarity between Rugaragara and Rucanzogera was (60%) (Fig.8; Appendix4).

Table 1:Shannon diversity index and evenness for the herbs species in 8 study sites of Gishwati side(July 2019).

Index	Corridor	Corridor control	Kinyenkada control	Kinyenkanda	Matyazo	Matyazo control	Rushubi	Rushubi control
Shannon H' Log Base 10.	1.004	0.803	0.754	0.794	0.728	0.847	0.947	0.749
Shannon Hmax Log Base 10.	1.279	0.903	0.903	0.954	1.114	1	1.204	0.903
Shannon J'	0.785	0.889	0.835	0.832	0.654	0.847	0.786	0.829

Table 2: Shannon diversity index and evenness for herbs species from 10 studies area of Mukura side (July 2019).

Index	Busoro2	Busoro 2 control	Ndaba	Ndaba control	Rucanzogera	Rucanzogera control	Rugaragara	Rugaragara control	Rwungo	Rwungo control
Shannon H'	1.275	0.789	1.01	0.713	1.032	0.776	0.963	0.73	1.176	0.74
Shannon Hmax	1.38	0.954	1.11	0.778	1.114	0.845	1.114	0.845	1.38	0.84
Shannon J'	0.924	0.827	0.91	0.916	0.926	0.919	0.864	0.864	0.852	0.87

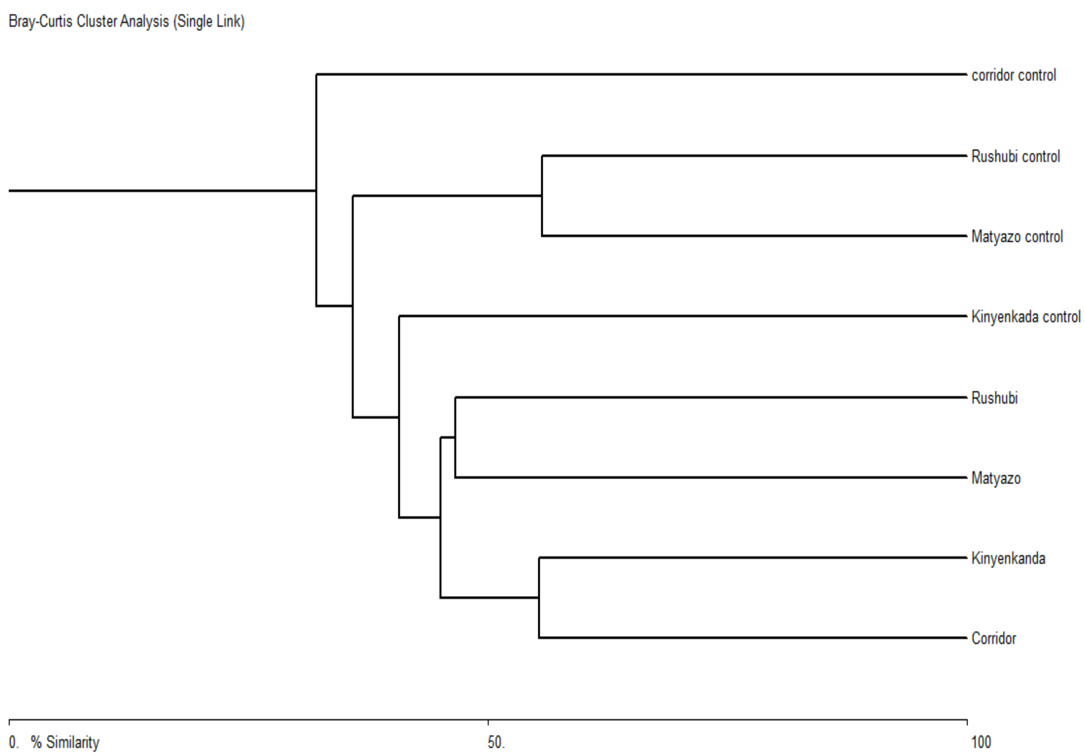


Figure 7: Herbs species similarity within 8 study sites in relation to their richness in the Gishwati side.

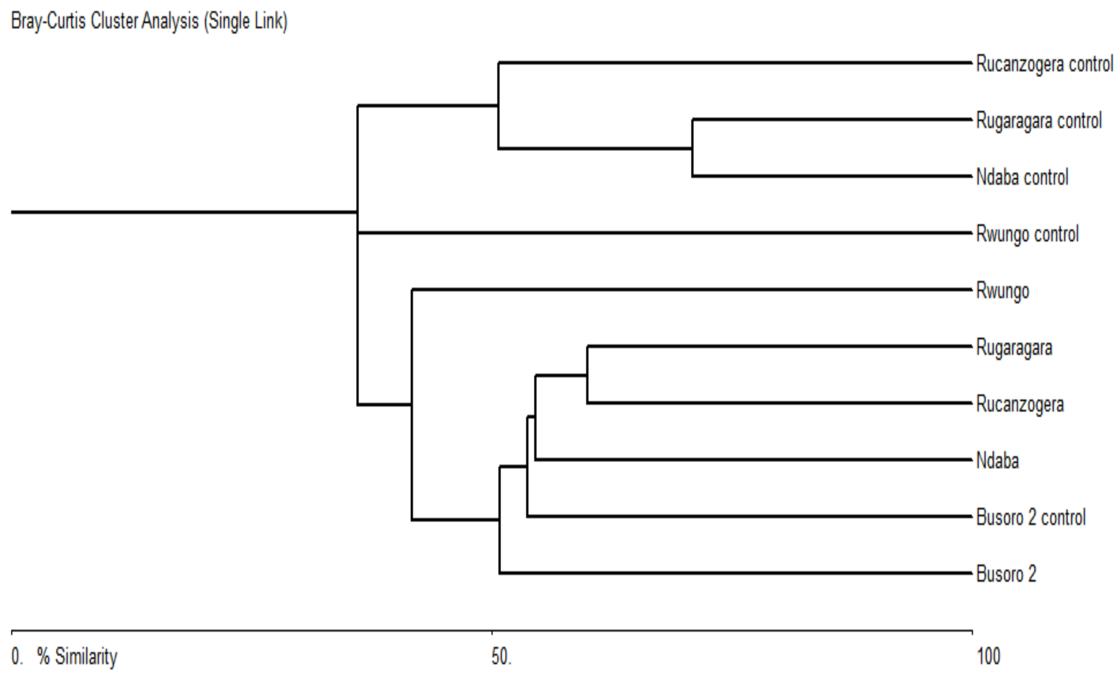


Figure 8: Herbs species similarity within 10 study sites in relation of their richness in the Mukura side

For the woody species (shrubs and trees) identified at Gishwati side the high Shannon diversity was observed at Matyazo followed by Rushubi and the smallest was Matyazo control (Table3). The sites of Mukura side, the maximum Shannon diversity was observed at Busoro2, and the small Shannon diversity was at Rwungo control (Table 4). In the Gishwati study sites the topmost similarity of the woody species abundance was observed between Corridor control and Matyazo control (90.54%) and followed by the similarity between Rushubi control and Matyazo control (70.68) (Fig. 9; Appendix 7). Where at Mukura side, the highest similarity was observed between Busoro2 control and Ndaba control (95.77%) and then the similarity between Ndaba control and Rugaragara control (95.38%) (Fig.10; Appendix 8).

Table 3. Shannon diversity index and evenness for woody species from 8 studies areas of Gishwati side (July 2019)

Index	Corridor	Corridor control	Matyazo	Matyazo control	Kinyenkanda	Kinyenkada control	Rushubi	Rushubi control
Shannon H' Log Base 10.	0.316	0.161	0.334	0.128	0.262	0.224	0.326	0.175
Shannon Hmax Log Base 10.	3.178	1.946	3.332	1.609	2.773	2.485	3.258	2.079
J'	0.099	0.083	0.100	0.080	0.095	0.090	0.100	0.084

Table 4. Shannon diversity index and evenness for woody species from 10 studies area of Mukura side (July 2019).

Index	Rugaragara	Rugaragara Control	Busoro2	Busoro2 control	Ndaba	Ndaba control	Rucanzogera	Rucanzogera control	Rwungo	Rwungo contro
Shannon H'.	0.2797	0.1629	0.35	0.182	0.25	0.172	0.2111	0.1487	0.24	0.04
Shannon Hmax.	4.3694	3.4340	5.05	3.610	4.18	3.526	3.8501	3.2958	4.12	1.79
J'	0.0640	0.0474	0.07	0.050	0.06	0.049	0.0548	0.0451	0.05	0.02

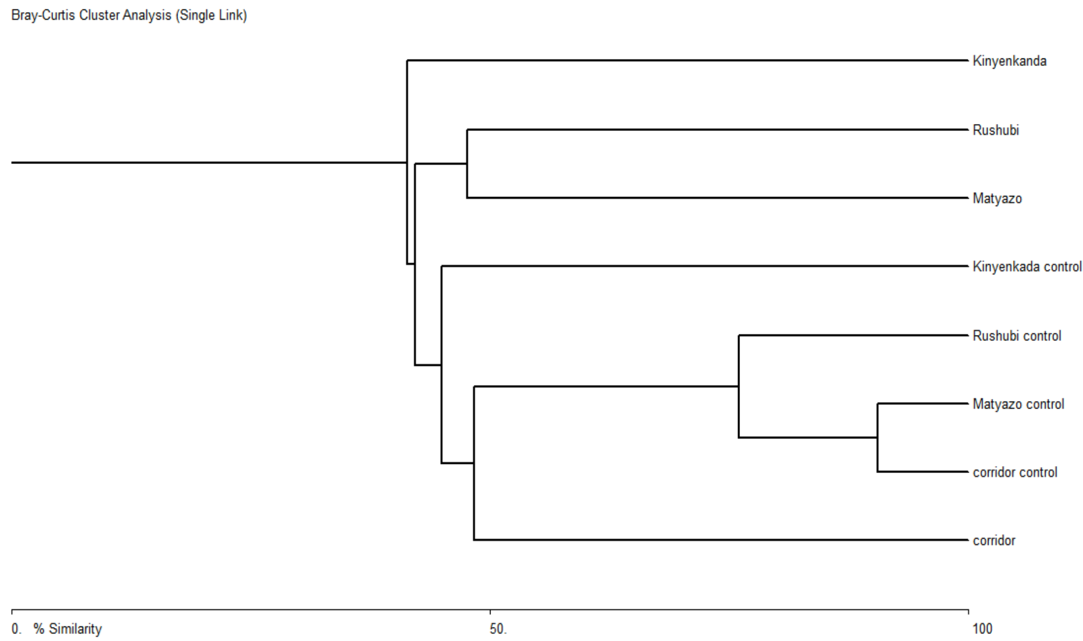


Figure 9: Woody species similarity within 8 study sites in relation to their richness in the Gishwati side.

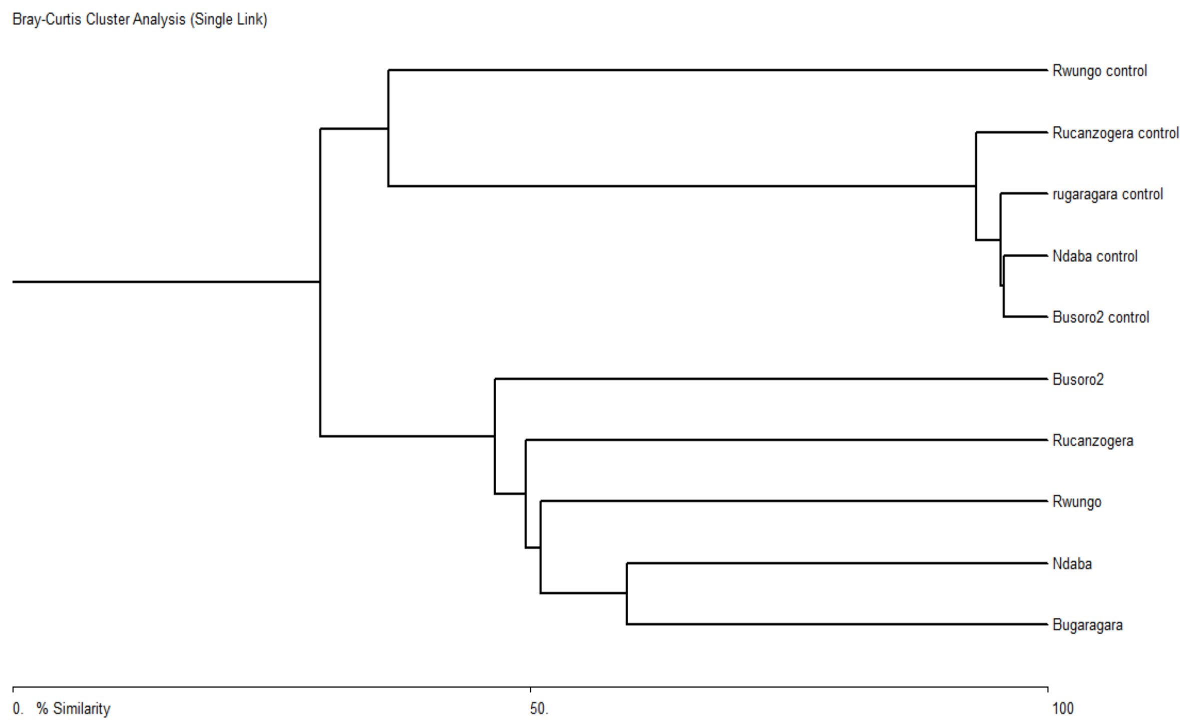


Figure 10: Woody species similarity within 10 study sites in relation to their richness in the Mukura side.

The rarefaction curves were used to compare the herbs species richness in Gishwati-Mukura National Park (Fig. 11 and 12). Corridor site is the most diverse followed by Rushubi site of Gishwati side. Mukura side, Busoro and Rwungo were the most diverse while the Ndaba control was the least diverse (Fig. 11and 12; Appendixes 1 and 2).

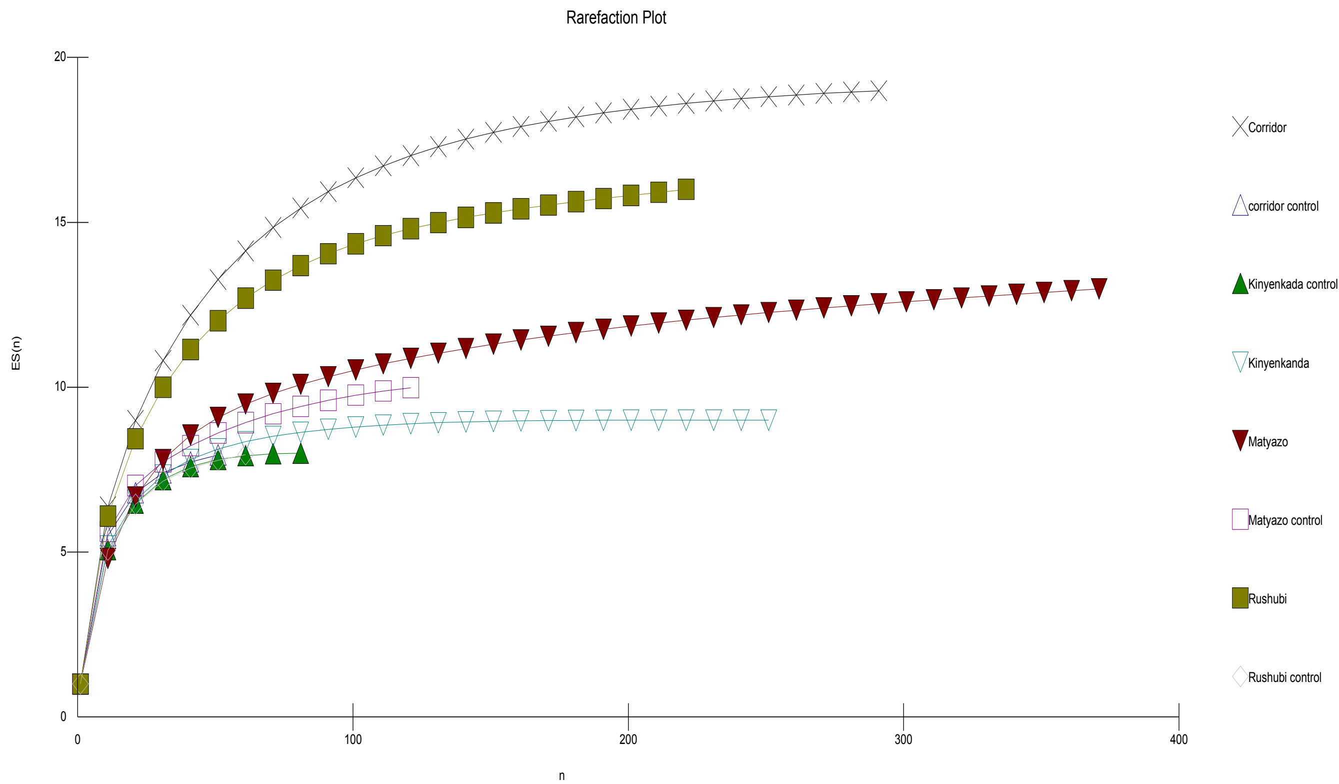


Figure 11. Rarefaction curve for the abundance of herbs species in 8 study sites of Gihwati side.

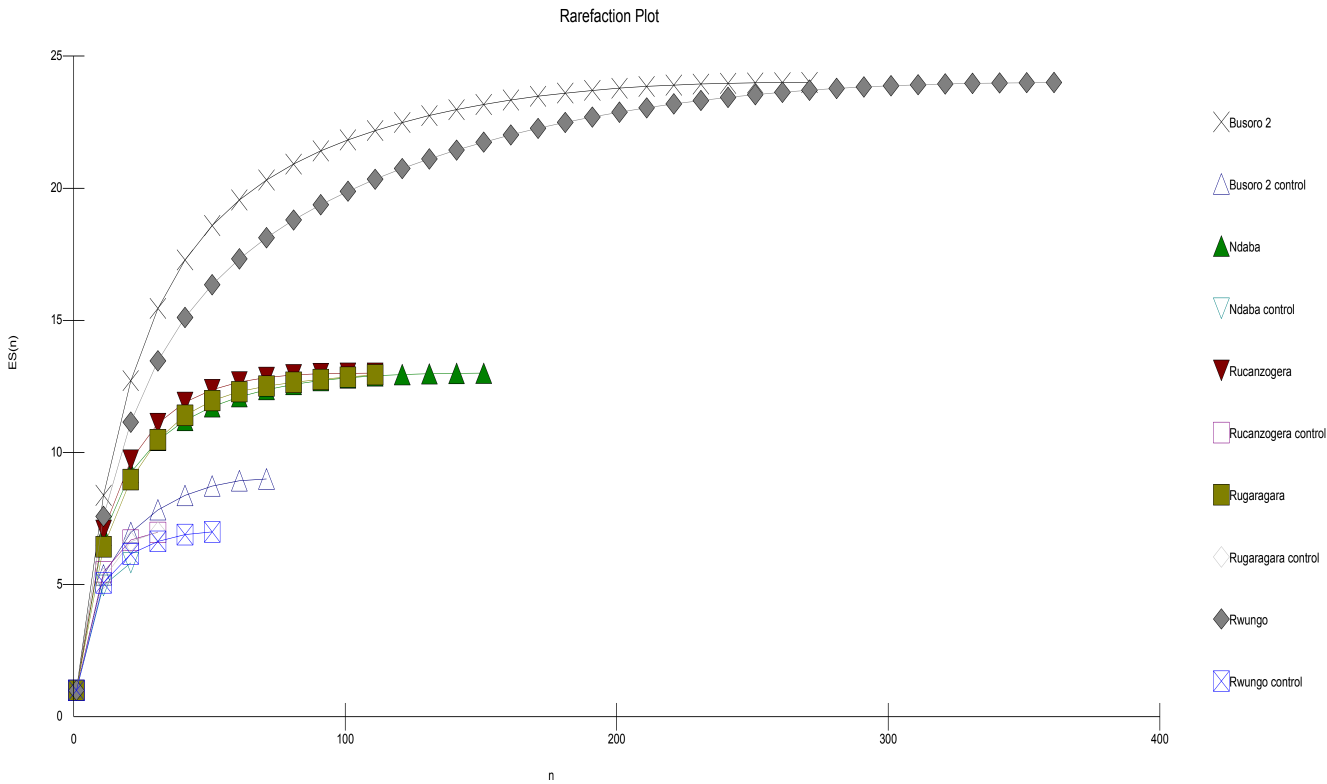


Figure 12. Rarefaction curve for the abundance of herbs species in 10 study sites of Mukura side.

For the woody species identified at different sites of Gishwati-Mukura National Park, the rarefaction curves showed the high richness woody species at Rushubi and followed by Matyazo of Gishwati side. Mukura side, Rugaragara and Busoro2 were highly diverse (Fig. 13and 14; Appendixes 1 and 2).

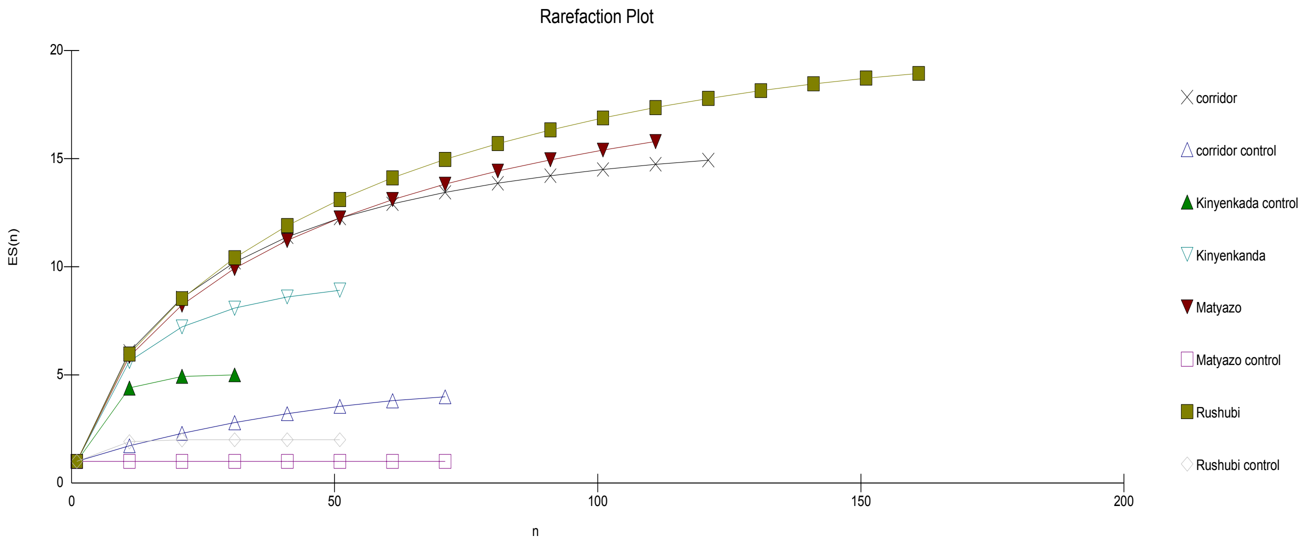


Figure 13: Rarefaction curve for the abundance of woody species in 8study sites of Gishwati side.

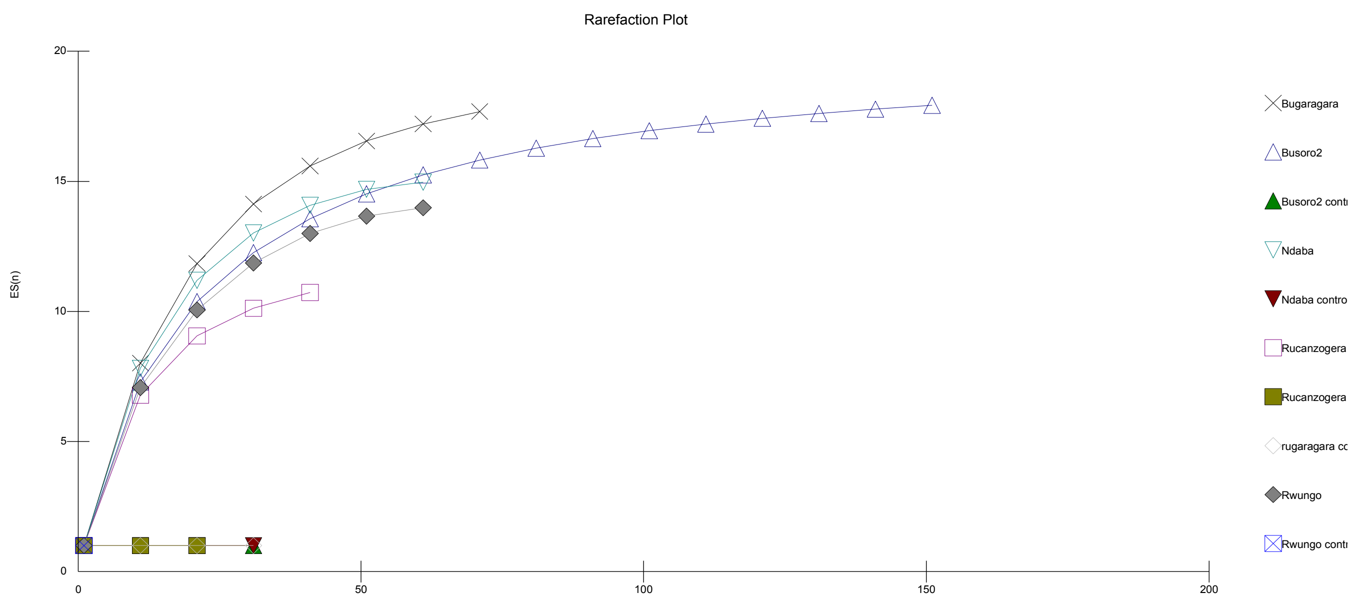


Figure 14:Rarefaction curve for the abundance of woody species in 10 study sites of Mukura side.

CHAPTER 5. DISCUSSION

5.1. Number of *Eucalyptus* stumps, *Eucalyptus* stumps coppiced and *Eucalyptus* seedlings

The *Eucalyptus* species removal in the Gishwati-Mukura National Park was done in 2016, and after 3 years total number of *Eucalyptus* stumps coppiced was 12 within 116 number of stumps identified at Mukura Gishwati side and 8 coppiced stumps out of 81 stumps at Mukura side (Fig.1 and 2) which were representing 10.3% and 9.8% respectively. This may be explained by the stumps debarking level and none debarked E. stumps which was followed by the several wood decaying fungi which attacked the stumps (Alonso et al., 2012). These results are comparable to what has been obtained by Alonso et al. (2012) who conducted the research on the development of the sprouted stumps of *Eucalyptus maidenii* and *Eucalyptus globulus* under different level of stumps debarking and they got 12.5% sprouted stumps that were still alive. The harvesting method, seasons (summer and winter), age of stumps, period stumps stay after cut and stumps damage had the high influence on the regeneration or coppicing of E. stumps ability (Daniel Pegoretti Leite de Souza, 2015). According to Alonso et al. (2012) the incidence of bark detachment decreases the number of the coppiced stumps, where no barks detachment resulted 100% of coppiced while 100% barks detachment resulted in 0% of the stumps coppiced. The rotting fungi can cover the whole surface of the E. stumps after the period of two years' harvest.

5.2. Number of *Alnus* seeds dispersed and seedlings germinated

The number of *Alnus* seeds counted was significantly decreased from the nearest of the tree stumps to 100m distance, whereas inside the park, 133 seeds were counted near the stump and none seed recorded at 75m (Fig. 3), this was due to the wind and gravity forces that pull out the seed of *Alnus* in the study area and the other displacement factors including the human being looking for the seeds for tree plantation (by human observation). The *Alnus* seed are winged that can be transported by wind and birds at the long distance (Cunnings et al., 2016).

The number of *Alnus* seedlings ranged at 15 to 36 seedlings which were recorded at 0 m to 15 m distance in the outside of the park respectively due to the ground disturbance, the soil exposed and the shading effect described as the conditions affecting the *Alnus* seed germination in the protected area (Tobita et al., 2015).

Thought inside the park there were high seedbank, there was no seed germinated due to the shading effect and no soil exposed. This result is in line with what Tobita et al., (2015)got during the analysis of the regeneration of 23 woody species including *Alnus* species where they recorded 0% of *Alnus* (alder) seedling on the forest flow and *Alnus* seeds did not germinate on the covered or mulched land, but germinated well in the cleared land (Anderson, 2014).

5.3. Native plant species diversity and richness in in the *Eucalyptus* removed area

The number of the herbs species identified in the E. removed site and in the control were significantly different in all study sites with 1142 in E. removed area and 324 in the control of Gishwati side and 1019 and 227 species number at Mukura side respectively (Table1 and 2). The big difference in term of herb species abundance is explained by the chemical substance in the E. leaves which cause the allelopathic effect on the native species, the shading effect and high competition with native species in the area (Chu et al., 2014), and the E. species harmed the native species which caused the extinction of the native species as well as decrease native species population size(Dyer, 1996). This is similar to Kasenene (2007)observation after the assessment of the number of native species return in the E. logged area and they observed the high number of native species regenerated in the harvested area compared to the unlogged area. Kasenene (2007) also found the high diversity of the pioneer species, and the secondary forest after the *Eucalyptus* harvesting with the high regeneration of native species was at 80%. In the harvested area shown the high regeneration of native species at 106% compare to 14.4% regenerated to unharvested area (Barua et al., 2017). The regeneration of the native species in the nature area required the sun light to reach on the ground, growth medium (soil) and viable seed to germinate (Park N.N., 2007). The seed dispersal factors (wind, bird, animal, etc) are also taken into consideration to high abundance and diverse plant species in the disturbed area due to the different seed treatment provided (Isabel & Pinto, 2018).

The woody species regenerated in the E. removed site and non-removed site were 380 natives and 76 non-natives and 378 natives and 33 non-native woody species were identified at Gishwati and Mukura sides respectively. There were high abundance of pioneer species than climax species, the pioneer species including *Macaranga kilimandscharica, Maesa lanceolata, Dombeya torida, Bothriocline ruwenzoriensi*, *Xymalos monospora, Apodytes dimidiate*, etc and some climax species like *Carapa grandiflora*, *Podocarpus falcatus, Syzygium guinense,* and *Myrianthus holstii* .The results also were in the line with what Kasenene (2007) observed on species regenerated on pre- and post-harvesting of tree species, whereas in the E. harvested area resulted the high number of pioneer tree species regenerated compared to climax tree species after seven years. Selwyn & Ganesan (2009) found high diversity of saplings regenerated in the cleared area at 88% compared to 54% saplings of non-cleared forest.

5.4. Plant species variability in the *Eucalyptus* removed area and the control of the study site

The plant species abundance in the E. removal and control sites of Mukura side varies within the plots. The report presented at Gishwati side, Corridor had high plant species abundance than Kinyenkanda control and Corridor control. At Mukura side, the plant species were highly abundant at Busoro 2 and Rwungo sites than Rwungo control and Rugaragara control (Appendixes 1and 2). These results are comparable to what Selwyn & Ganesan (2009) got by which the native species abundance in the cleared *Eucalyptus* plantation was 100 compare to 58 individual counts in the un-cleared E. plantation. Moreover, the E. removed sites were open and disturbed by the human activities which lead to the high growth of the understory compared to the covered ground. Fischer & Killmann (2008) noted that plants of Nyungwe National Park Rwanda, shown the high number of plants species identified in Gishwati-Mukura National Park distributed on the forest edge, open and disturbed areas. At Gishwati side, Corridor was highly diversifying at (Hmax = 1.279) with the high abundance of H'= 1.004 compare to other sites, this is due to the minimum soil surface disturbance and low colonization of *Pteridium aquilinum* (Tab 1). The Busoro2 and Rwungo had high diversity (Hmax= 1.38) with different herbs species abundance due different frequency of the species present in both sites, H'= 1.275 and H'= 1.176 (Tab.2). The matrix of similarity in the 8 study sites of Gishwati side, was described by the dendograms which is illustrating the similarities between E. species removed area and the control at Gishwati, Rushubi control and Matyazo control had high similarity due to the most present species for both sites were the same (Fig.7). At Mukura side, the great similarity was observed between Rugaragara control and Ndaba control. This is because the species present were all most the same even if the species abundance were nearly equal (Fig.8).

CONCLUSION AND RECOMMANDATIONS

The assessment of the impact of removing the *Eucalyptus* species on the nature regeneration of native species at Gishwati_Mukura National Park showed how plant species diversity and abundance were mostly distributed based on presence or absence of *Eucalyptus* on the study sites. The research detected that there were low E. stumps regenerated compared to the total number of the E. stumps and the regenerated stumps found that they did not debark and not managed the sprouted trees. The Eucalyptus seedlings in the study area also were few due to the unfavorable condition enabling them to germinate. The second question was about the number of native and non-native species return after E. species removal, their abundance and richness, the research detected the bigger difference between the plant species regenerated in the E. removed sites and the non-E. removed sites. The *Coelachne africana, Phyllanthus nummulariifolius* herbs and *Macaranga kilimandscharica, Maesa lanceolate* woody species were highly abundant in the E. removed sites of Gishwati_Mukura National Park and few of climax species like *Syzygium guinens*. Those species indicated the highly disturbed areas and woody plants were mostly regenerated first (pioneer species) then low abundance of the climax species on the cleared forest. The dendrograms shown that the study sites similarities of the plants species abundance and diversity varied significantly within the study sites of Mukura and Gishwati sides. The plant species were not distributed equally through the study sites of the Park, due to there was high abundance of the plant species in the E. removed sites than none E. removed sites. Moreover, the E. removed sites shown high plant richness compared to non-E. removed sites. The last question was about regeneration potential of *Alnus* species used as buffer zone of Gishwati side in and out the Park, the results shown that the *Alnus* seed was highly decreased far from the tree stump in and outside of the park caused by some seeds dispersal factors including wind and gravity. There was no *Alnus* seedlings germinated inside the parks while the outside in the pasture land the number of seedlings germinated was in the 15 m due to the favorable environmental condition enabling the seed to germinate were there during research (soil exposed, light and favorable humidity).

Based on the research findings, we recommend to the researchers in the biodiversity department to study on the effect of the *Acacia melanoxylon* trees species on the native species abundance and distribution at Gishwati-Mukura National Park. It is also needed to study the seasonal variability effect on the native species regeneration in the *Eucalyptus* removed sites at Gishwati- Mukura National park to see the effect of sun and rainfall effect on the regeneration. Lastly we recommend the researchers in soil sciences to conduct a study on the effect of the Exotic species on the soil properties modification toward the native species distribution and abundance in the Park, which will help the park managers to take a proper decision toward the exotic species management in the park for the ecosystem functioning and the park integrity.

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APPENDICES

Appendix 1: Statistical summary of the herbs species at Gishwati side

Sample	Mean Individuals	Variance	Standard Deviation	Standard Error	Total Individuals	Total Species
Koridoro	7.171	258.695	16.084	2.512	294	19
Koridoro control	1.317	11.372	3.372	0.527	54	8
Kinyenkada control	2.024	34.474	5.871	0.917	83	8
Kinyenkanda	6.146	276.378	16.625	2.596	252	9
Matyazo	9.146	1015.478	31.867	4.977	375	13
Matyazo control	3	52.95	7.277	1.136	123	10
Rushubi	5.39	166.744	12.913	2.017	221	16
Rushubi control	1.561	20.452	4.522	0.706	64	8

Appendix 2: Statistical summary of the herbs species at Mukura side

Sample	Mean Individuals	Variance	Standard Deviation	Standard Error	Total Individuals	Total Species
Busoro	0.929	1.044	1.022	0.158	39	24
Busoro control	0.405	0.979	0.989	0.153	17	9
Ndaba	0.571	0.983	0.991	0.153	24	13
Ndaba control	0.262	0.539	0.734	0.113	11	6
Rucanzogera	0.476	0.695	0.833	0.129	20	13
Rucanzogera control	0.31	0.609	0.78	0.12	13	7
Rugaragara	0.476	0.695	0.833	0.129	20	13
Rugaragara control	0.214	0.319	0.565	0.087	9	7
Rwungo	0.905	0.966	0.983	0.152	38	24
Rwungo control	0.286	0.551	0.742	0.114	12	7

Appendix 3: Similarity Matrix of herbs species at Gishwati side

	Corridor	Corridor control	Kinyenkada control	Kinyenkanda	Matyazo	Matyazo control	Rushubi	Rushubi control
Corridor	*	13.79	14.32	55.31	36.17	13.43	45.05	13.97
Corridor control	*	*	32.12	17.65	14.45	16.95	25.45	30.51
Kinyenkada control	*	*	*	7.16	15.72	35.92	40.79	24.49
Kinyenkanda	*	*	*	*	38.60	9.07	42.28	15.82
Matyazo	*	*	*	*	*	10.44	46.64	10.02
Matyazo control	*	*	*	*	*	*	16.28	55.62
Rushubi	*	*	*	*	*	*	*	16.14
Rushubi control	*	*	*	*	*	*	*	*

Appendix 4: Similarity Matrix of herbs species at Mukura side

	Busoro2	Busoro2 control	Ndaba	Ndaba control	Rucanzogera	Rucanzogera control	Rugaragara	Rugaragara control	Rwungo	Rwungo control
Busoro2	*	24.49	43.97	2.66	47.52	12.26	50.90	5.94	41.76	24.00
Busoro2 control	*	*	40.18	13.73	40.22	36.04	53.68	21.15	15.53	28.57
Ndaba	*	*	*	14.29	54.55	28.27	49.63	18.48	30.89	35.92
Ndaba control	*	*	*	*	23.94	49.28	5.41	70.97	6.57	4.76
Rucanzogera	*	*	*	*	*	34.44	60.00	27.78	33.47	34.94
Rucanzogera control	*	*	*	*	*	*	24.20	50.70	10.86	25.81
Rugaragara	*	*	*	*	*	*	*	12.00	31.41	36.05
Rugaragara control	*	*	*	*	*	*	*	*	11.06	13.95
Rwungo	*	*	*	*	*	*	*	*	*	18.10
Rwungo control	*	*	*	*	*	*	*	*	*	*

Appendix 5: Statistical summary of the woody species at Gishwati side

Sample	Mean Individuals	Variance	Standard Deviation	Standard Error	Total Individuals	Total Species
Corridor	4.172	75.719	8.702	1.616	121	14
Corridor control	2.483	154.259	12.42	2.306	72	4
Kinyenkada control	1.103	7.882	2.807	0.521	32	5
Kinyenkanda	1.897	16.025	4.003	0.743	55	9
Matyazo	4.034	73.034	8.546	1.587	117	16
Matyazo control	2.621	199.173	14.113	2.621	76	1
Rushubi	5.655	137.734	11.736	2.179	164	19
Rushubi control	1.966	78.463	8.858	1.645	57	2

Appendix 6: Statistical summary of the woody species at Mukura side

Sample	Mean Individuals	Variance	Standard Deviation	Standard Error	Total Individuals	Total Species
Rugaragara	2.724	10.207	3.195	0.593	79	18
Busoro2	5.414	57.68	7.595	1.41	157	18
Busoro2 control	1.276	47.207	6.871	1.276	37	1
Ndaba	2.276	7.993	2.827	0.525	66	15
Ndaba control	1.172	39.862	6.314	1.172	34	1
Rucanzogera	1.621	7.387	2.718	0.505	47	11
Rucanzogera control	0.931	25.138	5.014	0.931	27	1
Rugaragara control	1.069	33.138	5.757	1.069	31	1
Rwungo	2.138	11.623	3.409	0.633	62	14
Rwungo control	0.207	1.241	1.114	0.207	6	1

Appendix 7: Similarity Matrix of woody species at Gishwati side

	Corridor	Corridor control	Kinyenkada control	Kinyenkanda	Matyazo	Matyazo control	Rushubi	Rushubi control
Corridor	*	41.62	24.20	23.33	42.15	36.82	22.15	48.35
Corridor control	*	*	28.85	7.87	9.52	90.54	6.78	75.97
Kinyenkada control	*	*	*	41.38	29.53	20.37	10.20	44.94
Kinyenkanda	*	*	*	*	38.37	0.00	16.44	12.50
Matyazo	*	*	*	*	*	4.15	47.69	16.09
Matyazo control	*	*	*	*	*	*	4.17	70.68
Rushubi	*	*	*	*	*	*	*	6.33
Rushubi control	*	*	*	*	*	*	*	*

Appendix 8: Similarity Matrix of woody species at Mukura side

	Rugaragara	Busoro2	Busoro2 control	Ndaba	Ndaba control	Rucanzogera	Rucanzogera control	Rugaragara control	Rwungo	Rwungo control
Rugaragara	*	40.678	5.1724	59.3103	5.3097	36.5079	5.6604	5.4545	51.0638	7.0588
Busoro2	*	*	3.0928	46.6368	3.1414	34.3137	3.2609	3.1915	21.9178	3.681
Busoro2 control	*	*	*	3.8835	95.7747	26.1905	84.375	91.1765	0	27.907
Ndaba	*	*	*	*	4	49.5575	4.3011	4.1237	45.3125	5.5556
Ndaba control	*	*	*	*	*	27.1605	88.5246	95.3846	0	30
Rucanzogera	*	*	*	*	*	*	29.7297	28.2051	25.6881	22.6415
Rucanzogera control	*	*	*	*	*	*	*	93.1034	0	36.3636
rugaragara control	*	*	*	*	*	*	*	*	0	32.4324
Rwungo	*	*	*	*	*	*	*	*	*	0
Rwungo control	*	*	*	*	*	*	*	*	*	*

Appendix 9: Native herbs species abundance at Gishwati side

Comparison of herbs species identified in the Eucalyptusremoved area with the control at Gishwati side

Species	Corridor	Corridor control	Kinyenkada control	Kinyenkanda	Matyazo	Matyazo control	Rushubi	Rushubi control	Grand Total
Alchemilla johnstonii	0	0	4	0	0	23	0	8	35
Alectra sessiliflora	7	0	0	4	13	0	0	0	24
Asplenium friesiorum		0	0	0	0	0	1	0	1
Asplenium kuhnianum	15	0	0	0	0	0	0	0	15
Canarina eminii	10	0	0	0	0	0	0	0	10
clematis simensis	0	0	0	0	1	0	0	0	1
Coelachne africana	75	9	8	77	199	14	66	16	464
Crassophorum vitellinum	3	0	0	0	0	0	0	0	3
Cyanotis barabata	17	4	0	5	0	0	1	3	30
Drymaria cordata	7	0	0	0	0	2	6	0	15
Helichrysum foetidum	2	0	0	0	0	0	0	0	2
Helichrysum helvolum	4	0	0	0	0	0	0	0	4
Hydrocotyle mannii	0	0	0	0	0	14	0	0	14
Impatiens burtonii	0	0	0	0	0	0	3	0	3
Impatiens gesneroidea	0	0	0	0	0	0	5	0	5
Impatiens kagamei	0	0	0	0	0	0	5	0	5
Impatiens niamniamensis	0	0	0	0	0	0	12	0	12
Ipomea involucrata	12	0	0	11	19	0	11	0	53
Isachne mauritiana	0	0	10	0	0	28	0	0	38
Kyllinga stenophylla	0	8	31	0	5	0	40	0	84
lobelia gibberoa	0	1	0	0	0	0	0	0	1

Lotus becquetii	0	15	0	0	0	0	0	0	15
lycopodiella cernua	2	0	0	0	0	0	0	0	2
lycopodiella clavatum	60	0	0	0	0	0	0	0	60
lycopodium clavatum	45	0	0	42	0	0	0	0	87
Mariscus tomaiophyllus	0	0	0		0	0	0	3	3
Otiofora pauciflora	0	0	0	62	0	0	0	0	62
Otiophola pauciflora	0	0	2	0	0	0	0	0	2
Pennistum clandestinum	0	0	5	0	0	26	0	23	54
Phyllanthus nummulariifolius	15	3	19	0	40	9	34	0	120
Plantago palmata	0	0	0	0	0	4	0	5	9
Plectranthus serrulatus	0	0	0	0	3	0	0	0	3
Pneumatopteris afra	0	0	0	0	14	0	0	0	14
Pteridium aquilinum	4	3	4	14	18	1	4	1	49
Rubus steudneri	5	0	0	0	3	0	5	0	13
Rumex abyssinicus	1	0	0	0	0	0	0	0	1
Scleria distans		0	0	0	32	0	0	0	32
Senecio maranguensis	5	0	0	22	0	0	3	0	30
Senecio subsessilis	0	0	0	0	1	0		0	1
Solenostemon sylvaticum	0	0	0	0	0	0	9	0	9
Spermacoce princea	5	11	0	15	27	2	16	5	81
Grand Total	**294**	**54**	**83**	**252**	**375**	**123**	**221**	**64**	**1466**
Abundance of the species in the E. removed area	1142								
Abundance of the species in the controls	324								

Abundance of the species in the E. removed area per $1m^2$	57
Abundance of the species in the non-E. removed area	16

Appendic:10. ***Native herbs species abundance at Mukura side***

species	Busoro 2	Busoro 2 control	Ndaba	Ndaba control	Rucanzogera	Rucanzogera control	Rugaragara	Rugaragara control	Rwungo	Rwungo control	Total
A splenium friesiorum	3	0	0	0	0	0	0	0	0	0	3
Alchemilla ellenbeckii	8	0	0	0	0	0	0	0	2	0	10
Alchemilla johnstonii	0	0	4	4	6	3	0	2	0	0	19
Alectra sessiliflora	2	0	16	0	0	0	1	0	3	0	22
asplenium kuhnianum	0	0		0	0	0	4	0	0	0	4
botrioclyne longipes	12	0	6	0	0	0	0	0	0	0	18
brillanthaisia nitens	10	0	0	0	0	0	6	0	0	0	16
Carex conferta	0	0	0	0	0	0	0	0	3	0	3
Coelachne africana	18	28	18	0	18	13	29	0	15	6	145
Conyza welwitschii	0	0	0	0	0	0	0	0	2	0	2
Crassophorum paludum	0	0	0	0	0	0	0	0	3	0	3
cyanotis barabata	13	2	0	0	0	0	0	0	2	0	17
Digitaria abyssinica	0	0	0	0	0	0	0	0	15	0	15
drymaria cordata	25	0	19	0	3	0	4	0	0	0	51
Epilobium salignum	0	0	0	8	0	3	0	2	0	0	13
Helichrysum globosum	3	0	0	0	0	0	0	0	0	0	3
hypericum scioanum	15	0	0	0	0	0	0	0	15	0	30
impatiens burtonii	21	0	0	0	0	0	6	0	0	0	27
Ipomea involucrata	7	0	2	0	3	0	6	0	7	0	25

isachne mauritiana	0	0	0	0	0	0	0	0	0	8	8
Isodon ramosissimus	21	0	0	0	15	0	0	0	0	0	36
kyllinga appendiculata	0	0	0	0	0	0	0	0	3	0	3
kyllinga stenophylla	14	0	4	2	6	6	6	4	5	11	58
lindernia nummulariifolia	8	0	0	0	0	0	0	0	10	0	18
lobelia molleri	0	0	0	0	0	0	0	0	19	0	19
mimulopsis excellens	3	0	0	0	0	0	0	0	0	0	3
otiophora pauciflora	0	0	0	0	0	3	0	0	0	0	3
Panicum eickii	0	0	0	0	0	0	0	0	3	0	3
paspalum scrobiculatum	0	0	0	9	9	4	0	13	33	0	68
pennistum clandestinum	3	2	0	0	4	0	0	0	0	0	9
Phyllanthus nummulariifolius	31	2	17	0	20	0	28	2	28	2	130
Plantago palmata	2	0	0	0		0	0	0	0	0	2
plectranthus serrulatus	0	0	0	0	3	0	0	0	14	0	17
Pteridium aquilinum	3	10	0	0	0	0	7	0	0	2	22
pycreus nigricans	0	0	0	0	0	0	0	0	56	0	56
Rubus steudneri	0	3	0	0	0	0	0	0		0	3
Senecio maranguensis	6	0	10	0	8	0	4	0	24	6	58
Spermacoce princea	17	7	7	2	8	0	6	3	18	0	68
swertia usambarensis	14	0	0	0	0	0	0	0	16	0	30
Torenia thouarsii	0	10	27	5	0	7	0	6		0	55
vigna parkeri	0	0	3	0	0	0	0	0	4	0	7
Virectaria major	12	8	19	0	9	0	11	0	66	19	94
Grand Total	**271**	**72**	**152**	**30**	**112**	**39**	**118**	**32**	**366**	**54**	**1246**
Abundance of the species in the controls	227										
Abundance of the species in the E. removed area per $1m^2$	60										
Abundance of the species in the non E. removed area per $1m^2$	13										