LESOTHO CLIMATE CHANGE ADAPTATION PROJECT

# Ecosystems, Agriculture and Livelihoods in the Lesotho Highlands: Likely Futures and the Implications of Climate Change

Fonda Lewis, Jon McCosh, Catherine Pringle, Ian Bredin and Zibonele Nxele

Institute of Natural Resources NPC

**INR Report: Discussion Document**

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## *DISCUSSION DOCUMENT*

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In Association with

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# SUMMARY FOR DECISION MAKERS

The analysis of climate change information relied on the results from a study undertaken by Schulze (2010) from the Department of Bioresources Engineering and Environmental Hydrology at the University of KwaZulu-Natal. This study entailed the analysis of five Global Circulation Models (GCMs) using the A2 emissions scenario. Regional climate change scenarios were developed for "present", "intermediate future" and "more distant future" climates, represented by the following time periods:

- present climate: 1971 - 1990 (based on data from 1961 - 2000),
- intermediate future climate: 2046 - 2065, and
- distant future climate: 2081 - 2100.

Results for the following parameters were extracted from the Schulze (2010) study for use in the current project:

| Parameter | Variable |
|---|---|
| **Temperature** | Mean annual temperature |
| | January maximum |
| | July minimum |
| **Heat waves and cold spells** | Heat waves |
| | Extreme heat waves |
| | Cold spells |
| | Severe cold spells |
| **Precipitation** | Mean Annual Precipitation |
| | Median January Precipitation |
| | Median April Precipitation |
| | Median July Precipitation |
| | Median October Precipitation |
| | Rainfall concentration |
| | Rainfall seasonality |
| **Heat units and chill units** | Accumulated heat units - Annual |
| | Accumulated heat units - Summer |
| | Accumulated heat units - Winter |
| | Accumulated chill units - Winter |
| **Soil water stress** | No water stress |
| | Mild water stress |
| | Severe water stress |
| | Water logging |
| **Evaporation** | Mean annual reference crop evaporation |

The analysis indicated that projected changes in climate are likely to be similar across all PCAs. Mean annual temperatures are projected to rise, with increases being greater in the more distant future than in the intermediate future. These rising temperatures will have a profound effect on evaporation, with projections indicating a 10 - 15% increase in evaporation in the intermediate future and a 20 - 25% increase in the more distant future. Mean annual precipitation is projected to increase in the order of 100 to 200mm in the intermediate future and by up to 300mm in the more distant future. Increases in precipitation in all four cardinal months are also anticipated. Rainfall seasonality is likely to shift from mid-summer (January) to late-summer (February) and rainfall is expected to be more evenly distributed across the months but with a reduction in the amount of summer rainfall. The analysis also predicts a greater frequency of high intensity rainfall events. These increases in precipitation will have a direct impact on soil moisture with an increase in water logging projected in both the intermediate and more distant futures.

**Ecosystems**

Existing vegetation data gathered for the Lesotho Highlands Development Authority's 'Integrated Catchment Management' Project (ICM) was used as the baseline information for the assessment of vegetation communities throughout the four pilot sites. Ecosystem services were identified for each of the functional cover classes. Climate change and landscape variables most likely to impact on ecosystems were then identified, these included:

- Increased atmospheric carbon dioxide ($CO_2$) concentrations
- Increased temperature
- Change in precipitation patterns
- Reduced soil moisture stress in low-lying areas
- Increased evaporation
- Effect of aspect
- Effect of slope
- Altitude

Climate change and landscape variables were assessed and the following changes were projected:

- An increase in tree species within the lower altitudinal zones
- An increased distribution of shrubs
- An increase in temperate grass species
- A loss of wetland functionality
- A loss of biodiversity, with particular concern for the loss of endemic species in high lying areas

The impacts of climate change on ecosystem services within the pilot sites were then determined. Findings at a pilot site level identified a similar trend to the impacts of climate change. As a general trend there was an increase in some provisioning services such as building material and fuel resources, and a decrease in others, i.e. grazing and thatching. Most importantly, there was an overall loss of supporting and regulating services, such as water supply and sediment retention, which was of particular concern for wetland functionality. Cultural services were largely unaffected.

Implications of scenarios on ecosystem functioning

The assessment of the impacts of anthropogenic activities on ecosystem functioning and associated ecosystem services assumed a relationship between different scenarios and the utilization of different land capability classes. An historic change analysis of cultivated areas in 2001 versus those in 2010 indicated that higher capability classes (i.e. Classes I to IV) were cultivated first. Assuming that this trend is likely to continue into the future, the utilization of different capability classes was linked to different scenarios. Thus under the Rabbit scenario, capability classes I to IV were cultivated while under the Jackal scenario all capability classes were cultivated. Vegetation communities in these classes and ecosystem services associated with these communities were therefore lost or reduced as these areas were utilized.

The results of the scenarios indicated that three of the scenarios namely Tortoise, Jackal and Vulture displayed only minor reductions or slight increases in many provisioning services such as food production, fuel resources, thatching and grazing. Food production may increase in the short term as large areas are cultivated however poor management may result in overall reductions in yields in the long term. In addition, croplands still provide grazing, thatching and fuel resources however fuel resources in the form of *Artemesia* is usually only available from fields which have not been cultivated or are yet to be planted. Similarly, stover provides an important winter forage supply. Thus, while fuel resources and fodder may still be available from cultivated areas, these may only be available at certain times of the year in contrast the year round supply under natural conditions. Importantly however, these three scenarios displayed significant reductions in all regulating and supporting services as a result of the transformation to croplands coupled with unsustainable management practices. These change may have significant impacts on ecosystem functioning and reduce the resilience of the systems.

The Rabbit scenario however displayed only minor reductions in regulating and supporting services. Good governance structures which restrict the cultivation of all capability classes coupled with improved management result in increases in yields in the long term. In addition, under this scenario, large areas of natural vegetation remain and degraded areas are rehabilitated thereby contributing to ecosystem functioning. As a result, all ecosystem services persist at a reasonable level

<u>Combined impacts of scenarios and climate change</u>

The distribution of vegetation communities under climate change were modeled using key variables namely aspect, slope, altitude and proximity to water courses. Using GIS, these projected distributions were intersected with the capability classes to identify the relative contribution of the vegetation communities to each capability class. These areas were then reduced as capability classes were converted to croplands under each scenario and the contribution of the remaining areas to ecosystem services was calculated.

The results of the assessment indicated that anthropogenic impacts, rather than climate change, are the major driver of potential changes in ecosystem services. The effects of climate change may in some cases provide a slight buffer against pressures on ecosystem services associated with anthropogenic impacts. However this buffer is unlikely to translate into a positive trajectory for the supply of ecosystem services. The conversion of grasslands to shrublands will improve the supply of fuel resources and building materials however these benefits may come at the expense of available grazing. Under the Tortoise, Vulture and Jackal scenarios unsustainable management practices and the conversion of large tracts of natural areas to croplands is also likely to negate these benefits. However, increased temperatures and precipitation as a result of climate change may increase food production compared to these scenarios without climate change.

The Rabbit scenario which is characterized by good governance and access to resources illustrates only a slight reduction in regulating and supporting services compared to the other scenarios. Climate change impacts include expansion of shrublands, streambank vegetation, trees and alpine grasslands as a result of increased levels of $CO_2$ which when coupled with good management and minimal transformation result in improved grazing, more fuel resources, thatching and medicine. In addition, good management coupled with increased temperatures and precipitation is likely to result in increased food production in the long term although the risk of crop failure will be high. Climate change is however likely to result in the loss of rare and endemic species across all four scenarios.

**Agriculture**

Cropping systems in the Highlands of Lesotho are characterized by a smallholder rainfed production system with extremely limited inputs, a high reliance on maize production and by high yield variability between seasons. While the soils are good for agricultural production, they are typically low in nutrients and are in part responsible for the low yields experienced in the Highlands. Soil conservation systems are present, but are not sufficient to cope with extreme storms, which can cause major erosion from crop lands.

Livestock keeping is a deeply embedded cultural activity and livelihood strategy for highland communities. Sheep and goats make up the bulk of the livestock, in terms of numbers and many households also have cattle. Most households have few livestock (less than 30), while some individuals have large flocks and herds (in excess of 300). The grazing lands in the Highlands are widely considered to be overstocked, which places considerable pressure on the grazing resources. While livestock management systems, such as Rangeland Management Areas and Grazing Associations have been established they have had limited success in managing livestock and grazing patterns.

The key changes in climate that are predicted for the Highlands of Lesotho that are relevant to agriculture are an increase in temperature and an increase in rainfall. The increase in rainfall will be typically expressed as more frequent high intensity rainfall events (storms) with extended dry periods in between. The timing of rainfall is also expected to shift from a mid-summer peak rainfall to a late summer peak rainfall climate. So, while there is an overall increase in rainfall, the manner in which it increases is likely to have negative consequences for crop and rangeland production if current systems remain unchanged. The impact of climate change on crop and livestock production systems, and consequently livelihoods will be severe if existing cropping and land use systems remain unchanged. This will be reflected in reduced crop yields and increased crop failure due to increasing climate variability in the case of farming. In the case of livestock, there will be a decline in livestock quality and condition, reflecting a decline in the condition of forage resources in the rangelands.

There are however a number of progressive agricultural practices which, if properly adopted and supported through policy and extension support, can reduce the risk of crop failure in bad years and even increase crop production in good years. These interventions and adaptations will be explored in the next phase of this Project.

**Livelihoods and vulnerability**

Households in the Lesotho Highlands are heavily resource dependent. Households' livelihood strategies are largely undiversified and households largely rely on primary agricultural production to meet their livelihood needs. Crop production (with maize as the staple crop) and livestock production form the foundation of the livelihoods of households in the Highlands. Harvesting of resources from the wild (fuel materials, building materials, water, plants and medicines) are also critical for meeting the daily nutritional and survival needs.

High poverty levels mean that households have very little reserves to fall back on in times extreme events or shocks (such as droughts, floods or extreme snow events). This makes households very vulnerable to any changes in conditions that affect their ability to grow crops, keep livestock, or access natural resources. Potential future scenarios of livelihoods in the Highlands indicate that one characteristic in particular would likely improve the conditions for households, namely livelihood diversification. This could be catalyzed through access to capital and financing together with improved skill levels and capacity. Diversified livelihood strategies reduce the resource dependency of households and help them to cope more effectively during vulnerable times. Social cohesion and a stable and effective governance system also contribute to resilient and less vulnerable livelihoods for households in the Highlands. Even the absence of finance for investment and improved skill levels, social stability and cohesion still results in a relatively positive future scenario in the Highlands. However the households remain highly vulnerable as they have very little capacity to cope with shocks or changes. The final two scenarios paint very bleak futures in the Highlands. With no livelihood diversification, finance, skills and an unstable / unstructured social system in particular, conditions deteriorate to a classic ‘tragedy of the commons’ scenario with households maximizing short term benefits from the environment at the expense of long term sustainability. This environmental degradation contributes to a deterioration in ecosystem functioning and the loss of critical ecosystem services which ultimately also compromises the productivity of the environment and therefore agricultural yields. This becomes a downward spiral in both scenarios, as the majority of households are highly dependent on primary production for agriculture as the key livelihood strategy. As provisioning services and productivity are eroded, so too is the resilience of households and their ability to sustain themselves.

The trends illustrated in the three large negative scenarios (Tortoise, Vulture, Jackal) do not improve when superimposed with the climate change predictions for the Lesotho Highlands. Negative conditions are exacerbated by the increasing seasonality of returns and benefits from ecosystem services. Any positive conditions in the three negative scenarios are eroded by the compounding of environmental degradation and breakdown in social cohesion. Under the only largely positive scenario (Rabbit) household livelihood strategies are made more vulnerable by climate change impacts as a result of increasing seasonality of returns and benefits from ecosystem services and the need for investment and collaboration to manage and rehabilitate environmental degradation.

In conclusion, if households in the Highlands are already (as a result of relatively high poverty levels) in a position where they cannot themselves to break the dependency on traded off short term provisioning services against long term regulating and supporting services, then how will they be able to improve their coping and adaptation capacity to deal with climate change in future? A review of the likely future scenarios in the Lesotho Highlands, and the overlaying of these with climate change scenarios highlights that livelihood diversification, social cohesion, and effective governance are some of the most critical factors that will influence households ability to cope and adapt to the impacts of climate change. These will be explored in more detail in the next phase of the project and inform the identification and design of adaptation strategies.

# 1 INTRODUCTION AND BACKGROUND

Resource dependent households will be particularly vulnerable to the impacts of climate change, as they will have little to buffer themselves from the shocks and stresses that are predicted to be associated with climate change. Climate change scenarios for Lesotho predict warmer climatic conditions, lower precipitation in spring and summer, and higher precipitation in winter. These changes will have serious implications for agro-ecological conditions (LMS, 2001). These changes will significantly impact on the livelihoods of the vulnerable rural communities in Lesotho, particularly those in the mountain Highlands. Climate driven changes livelihoods and the environmental will potentially undermine not only the resilience of household livelihoods in the Highlands but also ecosystem functioning and the provision of critical ecosystem services, such water retention capabilities and streamflow regulation services vital for moderating downstream flow and preventing floods.

The Lesotho Highlands Water Project (LHWP) is located in the mountain catchments of the Lesotho Highlands. The LHWP involves the capture and storage of water in Lesotho's mountain Highlands, and transfer of this water to South Africa with South Africa paying royalties to Lesotho for the water. The LHWP therefore contributes significantly to the economy of Lesotho, as well as to water security and economic development in South Africa. The long term sustainability of the benefits from the LHWP will be negatively impacted by climate change if adaptation measures are not implemented to improve the ability of the mountain communities to respond to climate change in ways that benefit the environment and improve local livelihoods.

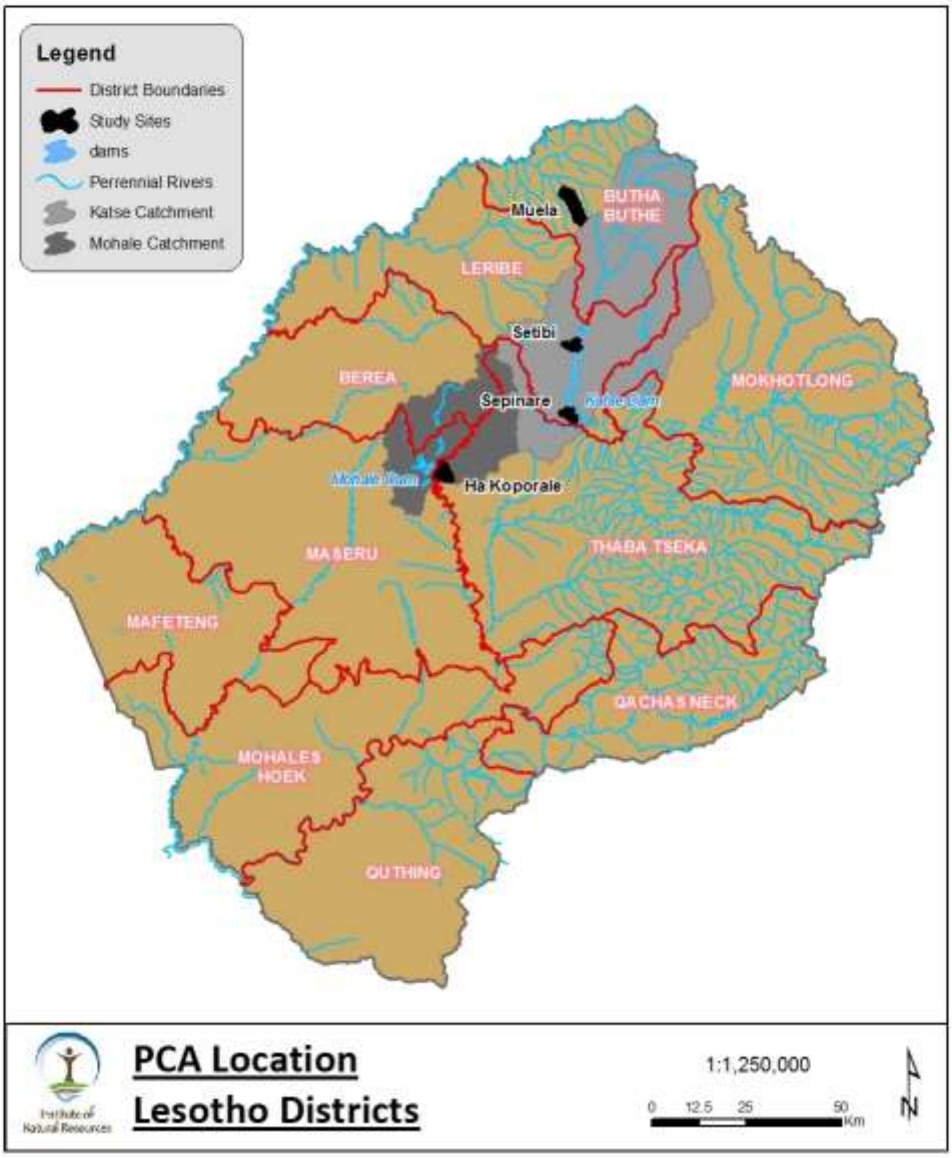
Lesotho covers an area of 30 352km$^2$, and is dominated by rugged topography of the Maloti and Drakensberg Mountain Ranges. The mountain region of Lesotho makes up approximately 60% of the country (LSM, 2007). The population of Lesotho is estimated to be 2 million, with approximately 24% of the population residing in the mountain zones which are characterized by relatively high levels of poverty. These mountain communities are dependent on livestock and crop production to support their livelihoods. The mountain zones are characterized by high livestock numbers, food insecurity, high degradation of indigenous vegetation and deterioration of rangelands, and extreme cold conditions (LMS, 2001).

Climate change could have severe consequences for both the people and natural environment in the Lesotho Highlands. Lesotho has called for assistance to ease livelihoods of communities who are subjected to greater challenges due to climate change (LMS, 2007). The inability of communities in the mountain zones of Lesotho to adapt in the face of the impacts of climate change not only threatens their own livelihoods, but also the production of water from the catchment, which sustains the LHWP, and which in turn affects the economy of Lesotho as well as South Africa.

The overall goal of this project is to build capacities of local communities, NGO networks and government departments in order to understand and adapt to the likely impacts of climate change in the mountain catchment areas of Lesotho. The initiative aims to achieve this by tackling the interrelated issues of poverty, environmental degradation and biodiversity loss.

The Lesotho Climate Change Adaptation Project (LCCA) is being undertaken at four sites (Figure 1.1.1). These sites were identified for the Integrated Catchment Management Project that was implemented by the Lesotho Highlands Development Authority in association with SMEC. The projects sites, as shown in Figure 3 are described as follows (SMEC, 2010):

- **<u>Ts'iu-Koporale pilot area</u>** in the Mohale catchment is made up of ten sub-villages. The total household population is estimated at 308, and is located in eth Thaba Tseka District**.**
- **<u>Setibi-Mamohau pilot area</u>** in the Katse catchment is made up of six sub-villages. This PCA is within the Leribe District. It has a household population of approximately 553, and is located in the Leribe District.
- **<u>Sepinare-Kosetabole pilot area</u>** in the Katse catchment is made up of two sub-villages and has a household population of 286, and is located in the Leribe District.
- **<u>'Muela PCA pilot area</u>** is also in the Katse catchment and is made up of eight sub-villages. There is a total household population is 557, and is located in the Botha Bothe District. This is the only pilot catchment that is situated in the Lesotho lowlands.




**<u>Figure 1.1.1</u>:** Location of the Pilot Catchment Areas (PCAs)

This report reflects progress on the initial phase of this Climate Change Adaptation Project, which focused on understanding livelihoods and ecosystem functioning in the Lesotho Highlands order to identify potential risks and vulnerabilities associated with the predicted changes to the climate. This information will inform the identification of key adaptation strategies and interventions that could be undertaken to households to cope and adapt to the impact of climate change so as to maintain livelihood resilience and protect ecosystem functioning.

# 2 PROJECT APPROACH TO ASSESSING ECOSYSTEMS SERVICES AND LIVELIHOODS

## 2.1 Biophysical assessment

### Approach to determining the impacts of climate change on ecosystem functioning

#### *2.1.1.1 Methodology for determining the impacts of climate change on ecosystem functioning*

The selection of pilot sites for the project was largely influenced by the availability of existing data, which would provide an insight into species composition and condition of the rangelands throughout the Lesotho Highlands. As part of LHDA's ICM Project (SMEC, 2010), a resource inventory was undertaken, which included a grazing areas and vegetation assessment (SMEC, 2010a). The findings from the grazing areas and vegetation assessment were used as the primary data source for species composition and veld condition throughout the four pilot sites.

The methodology used to interpret existing data and determine the associated ecosystem services for each of the vegetation communities and land cover classes, included:

- Evaluating all vegetation types and land cover classes identified in the grazing areas and vegetation assessment undertaken for the ICM project (SMEC, 2010a). This was undertaken by assessing the distribution of the vegetation types both at a desktop level (i.e. assessing aerial photography) and within the field. Site visits to briefly assess the vegetation types were undertaken at all of the four pilot sites;
- Grouping the vegetation types into vegetation communities according to dominate species and ecosystem services. Thirty seven vegetation types and land cover classes were identified for the ICM project (SMEC, 2010a). For the purposes of this study, these cover classes were grouped into 14 vegetation communities and land cover classes (i.e. functional cover classes), namely:
    - *Themeda-Festuca* grasslands;
    - *Aristida-Eragrostis-Artemesia* degraded grasslands;
    - *Harpochloa* grasslands;
    - Alpine grassland;
    - *Hyparrenhia* grasslands;
    - *Felicia-Chrysocoma* shrublands;
    - *Buddleja* shrubland;
    - *Leucosidea* shrubland;
    - Trees;
    - Streambank vegetation;
    - Wetlands;
    - Rocklands/Rocksheets;
    - Cultivation; and
    - Settlement and infrastructure

  Refer to Appendix A for a list of the vegetation types grouped into the above functional cover classes. The grouping of vegetation types was necessary to align vegetation types with similar ecosystem services;

- Determining and evaluating the provisioning, supporting, regulating and cultural services supplied by each of the vegetation communities and land cover classes. This was undertaken at both a desktop level, through reviewing of literature of supporting and regulating services within the context of the Lesotho Highlands, and through visiting each of the pilot sites and engaging with the local communities to identify 'first-hand' some of the provisioning and cultural services they obtain from the surrounding ecosystems; and
- Workshops with Lesotho partners and government ministries / departments, and grassland specialists, to verify the grouped vegetation communities and their associated ecosystem services. Workshops were conducted in Lesotho and South Africa.

The methodology applied to identifying the projected impact of climate change on the functional cover classes and their associated ecosystem services, included:

- Identifying key climate change variables that are projected to have the greatest impact on vegetation communities in the Lesotho Highlands. These variables were identified through assessing available climate change models (Schulze, 2010) and reviewing literature, and work-shopping the findings with climate change, vegetation and ecosystem service specialists. The key climate change variables included:
    - Increased atmospheric carbon dioxide ($CO_2$) concentrations;
    - An increase in temperature;
    - Change in precipitation;
    - Soil moisture stress; and
    - Evaporation.
- Assessing the key landscape variables that affect the distribution of vegetation communities throughout the Lesotho Highlands. These included:
    - Altitude;
    - Aspect; and
    - Slope.
- Establishing the impact climate change and landscape variables will likely have. This included grouping functional cover classes into broad vegetation communities that would represent the cover classes at a level at which projected changes are likely to occur. These projected changes included:
    - An increase in tree species within the lower altitudinal zones;
    - An increased distribution of shrubs;
    - An increase in C3 temperate grass species;
    - A loss of wetland functionality; and
    - A loss of biodiversity, with particular concern for the loss of endemic species in high lying areas.
- The projected impacts of climate change were linked back to the supply of ecosystem services from the broad vegetation communities. This was undertaken at a superficial level to simply identify the potential extent of the increase or decrease in ecosystem services;
- The projected impacts of climate change were then linked back to the supply of ecosystem services within the pilot sites. This was undertaken, using GIS software, by identifying the most likely or rather most suitable areas for baseline vegetation communities to expand into (according to the projected changes), which included assessing:
    - Aspect;

  - Slope;
  - Altitude; and
  - Distance from a watercourse.

  Each of these variable were considered for the baseline vegetation communities and based on the preferred variables (i.e. the vegetation community occurs above 2900m on slopes greater than 20° and on north facing slope) suitable adjacent alternatives were selected. The rules applied to establish the projected expansion or decrease in baseline vegetation communities are provided in Appendix B. This provided a platform to substantiate the increase or decrease of vegetation communities within the pilot sites according to the projected climate change impacts. Maps of the projected shifts in vegetation communities throughout the pilot sites are provided in Appendix D.
- The changes in the distribution of vegetation communities were then linked back to the supply of ecosystem services. A direct relationship of an increase or decrease in the area of a vegetation community was assumed to correspond to an increase or decrease in ecosystem services. Although this approach was a simplification of interactions within an ecosystem, it provided an indication of how climate change is projected to affect ecosystem services.

#### *2.1.1.2 Description of functional cover classes*

For the purpose of this study, functional cover classes included the vegetation communities, derived from the grouping of vegetation types, and the land cover classes identified in the ICM Project (SMEC, 2010). Each of the vegetation communities and land cover classes are described below, with Table 2.1.1 indicating the areas within each of the four pilot sites. For figures illustrating the distribution of the functional cover classes throughout the pilot sites refer to Appendix C.

**Table 2.1.1**: Areas (ha and %) of the functional cover classes within the four pilot sites

| Vegetation Community / Land Cover Class | Pilot Sites | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Muela | | Setibi | | Sepinare | | Koporale | |
| | Ha | % | Ha | % | Ha | % | Ha | % |
| ***Themeda-Festuca* Grasslands** | 215.3 | 7.5 | 206.2 | 20.1 | 129.5 | 12.7 | 294.6 | 14.7 |
| ***Aristida-Eragrostis-Artemesia* Degraded Grasslands** | 19.2 | 0.7 | 213.9 | 20.8 | 309.3 | 30.4 | 494.2 | 24.6 |
| **Harpochloa Grasslands** | 38.1 | 1.3 | 46.2 | 4.5 | 102.3 | 10.1 | 432.5 | 21.5 |
| ***Felicia-Chrysocoma* Shrublands** | 138.7 | 4.9 | 52.5 | 5.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Alpine Grassland** | 39.6 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| ***Hyparrenhia* Grasslands** | 518.9 | 18.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Rocklands/Rocksheets** | 460.6 | 16.2 | 70.3 | 6.8 | 62.3 | 6.1 | 166.1 | 8.3 |
| ***Leucosidea* Shrubland** | 552.5 | 19.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| ***Buddleia* Shrubland** | 177.5 | 6.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Trees (Poplar)** | 4.0 | 0.1 | 8.4 | 0.8 | 2.5 | 0.2 | 0.4 | 0.0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Settlement & Infrastructure** | 134.5 | 4.7 | 77.2 | 7.5 | 35.7 | 3.5 | 128.8 | 6.4 |
| **Streambank Vegetation (Salix)** | 61.5 | 2.2 | 10.8 | 1.0 | 0.0 | 0.0 | 13.5 | 0.7 |
| **Wetlands** | 41.6 | 1.5 | 41.2 | 4.0 | 38.5 | 3.8 | 81.7 | 4.1 |
| **Cultivation** | 450.1 | 15.8 | 301.3 | 29.3 | 336.2 | 33.1 | 397.5 | 19.8 |

**Areas indicated are according to the findings of the vegetation assessment for the ICM project (SMEC, 2010a). Refer to Appendix A.*

***Themeda-Festuca* Grasslands**

*Themeda-Festuca* Grassland included the following vegetation types:

- <u>*Themeda-Festuca* Climax Grassland</u> (SMEC, 2010a) - This is the climax vegetation type typical of cool, steep south-facing slopes. The dominant grass is *Themeda triandra* (Sebuko). As altitude increases *Themeda triandra* is replaced by *Festuca caprina* (Letsiri) as the dominant species. *Festuca caprina* is as productive as *Themeda triandra* but seems to be slightly less palatable. Common grasses include *Festuca caprina*, *Helictotrichon turgidulum, Merxmuellera disticha* (Moseha) and *Pentaschistis setifolia (*Lenyane). This vegetation type is the most preferred type for optimum grazing. A grazing capacity of 5 ha/LSU was assigned to this vegetation type.
- <u>*Themeda-Heteropogon-Trachypogon* Dry Climax Grassland</u> (SMEC, 2010a): This vegetation type is on steep, warm and dry, north-facing slopes, and is characterized by a combination of grasses which include *Themeda triandra, Heteropogon contortus* and *Trachypogon spicatus*. Under overgrazing, *Aristida junciformis* and *Elionurus muticus* generally increase. A grazing capacity of 10 ha/LSU was assigned to this vegetation type.
- <u>*Festuca-Pentaschistis-Themeda* Sub-Alpine Grassland</u> (SMEC, 2010a): This grassland type characterizes the vegetation on cold south-facing slopes above approximately 2500 m and indicates the transition of Sub-tropical Grasslands to Temperate Grasslands, although at some locations *Festuca caprina* (Letsiri) is the dominant grass at altitudes as low as 2450 m on sheltered south-western-facing slopes. According to Morris *et al.* (1993) *Festuca caprina* Grasslands are not characteristic of warmer and drier northern slopes. *Pentaschistis setifolia* may become dominant in extremely cold sheltered slopes. Other common species include *Merxmuellera disticha*, *Themeda triandra*, *Koeleria capensis* and *Helictotrichon turgidulum*. *Harpochloa falx* is a common species of rocky slopes and crests within the *Festuca-Pentaschistis-Themeda* Sub-Alpine Grassland. A grazing capacity of 5 ha/LSU was assigned to the vegetation type, similar to the *Themeda-Festuca* Climax Grassland.

**Figure 2.1.1:** *Themeda-Festuca* Grasslands

***Aristida-Eragrostis-Artemesia*** **Degraded Grasslands**

*Aristida-Eragrostis-Artemesia* Degraded Grasslands included the following vegetation types:

- *Aristida-Helictotrichon* Moist Degraded Grassland (SMEC, 2010a): This grassland occurs on overgrazed, moderate altitude, cool south-facing basalt slopes in the Muela catchment. The common grass species are amongst others *Aristida junciformis* (Lefielo), *Eragrostis chloromelas* (Tsane) and *Helictotrichon turgidulum*. The vegetation type is indicative of overgrazed conditions. Under better veld management the climax vegetation should have been dominated by *Themeda triandra*. A grazing capacity of 10 ha/LSU was assigned to the grazing area due to the unpalatability of the grass composition and the general steepness of the terrain.
- *Aristida-Pentzia-Felicia muricata* Eroded Grassland (SMEC, 2010a): Extremely eroded and degraded areas are characterized by the grasses *Aristida diffusa, Aristida junciformis, Eragrostis chloromelas* and *Catalepis gracilis*. *Felicia muricata* is frequently the dominant shrublet. Other typical shrub species include *Felicia filifolia*, *Chrysocoma ciliata*, *Pentzia cooperi* and *Artemisia afra*. This grazing area is associated with rangelands around villages at lower altitudes. A grazing capacity of 16 ha/LSU was assigned to the vegetation type.
- *Eragrostis chloromelas-Aristida junciformis* Degraded Grassland (SMEC, 2010a): The *Eragrostis chloromelas-Aristida junciformis* Degraded Grassland is typical of north-facing slopes at Setibi. *Eragrostis* species (*E. chloromelas, E. curvula and E. plana*) and *Aristida junciformis* are the dominant species, together with a less dominant shrub component consisting of *Helichrysum odoratissimum* (Imphepho), *Senecio othonniflorus*, *Chrysocoma ciliata* and *Pentzia cooperi*. A grazing capacity of 13 ha/LSU was assigned to the vegetation type.
- *Artemisia-Eragrostis* Degraded Grassland (SMEC, 2010a): The *Artemisia-Eragrostis* Degraded Grassland is associated with cultivated land and long-term anthropogenic impacts at lower altitudes, for example river valley slopes. Although *Artemisia afra* (Lengane) is a characteristic species on both the northern and southern aspects, the shrub is particularly dominant on cool and moist southern slopes. It is normally accompanied by the grasses *Eragrostis curvula* and *Aristida junciformis* and on severely degraded slopes by *Aristida diffusa*. At moist sites, the grasses *Agrostis lachnantha*, *Helictotrichon turgidulum* and *Bromus* species were found to be common as well as the shrublets *Senecio othonniflorus*,

*Helichrysum odoratissimum* and *Cineraria dieterlenii*. A grazing capacity of 13 ha/LSU was assigned to the vegetation type.

**Figure 2.1.2:** *Aristida-Eragrostis-Artemesia* Degraded Grasslands

***Harpochloa* Grasslands**

*Harpochloa* Grasslands included the following vegetation types:

- *Harpochloa falx-Eragrostis capensis-Themeda triandra* Short Grassland (SMEC, 2010a): This vegetation type is generally associated with gentle undulating slopes at lower altitudes. The soils are predominantly shallow and rocky, therefore the vegetation is a short dense grassland consisting of *Harpochloa falx* (Lefokolodi), *Eragrostis capensis* and *Themeda triandra*. Bare open rock sheets bordered by *Catalepis gracilis* are common. *Eragrostis racemosa* and *Elionurus muticus* (Sehloko) are more common species in overgrazed forms of this vegetation type. The vegetation type was assigned a grazing capacity of 10 ha/LSU.
- *Harpochloa falx-Catalepis gracilis* Short Grassland (SMEC, 2010a): *Harpochloa falx-Catalepis gracilis* Short Grassland is a similar vegetation type to the *Harpochloa falx-Eragrostis capensis-Themeda triandra* Short Grassland. It is the typical vegetation type associated with higher altitude mountain crests. Typical grasses are *Harpochloa falx*, *Catalepis gracilis* and *Aristida junciformis*. *Eragrostis capensis* and *Eragrostis racemosa* are not common species. The vegetation is frequently overgrazed and sparse. *Harpochloa falx* can also occur as homogenous lawn-like patches among bare rock sheets partially covered by *Catalepis gracilis*. Shrublets such as *Pentzia cooperi, Felicia filifolia* and *Gymnopentzia bifurcata* (Sehalahala) characterize severely overgrazed mountain crests. A grazing capacity of 13 ha/LSU was assigned.

**Figure 2.1.3:** *Harpochloa* Grasslands

***Felicia-Chrysocoma* Shrublands**

*Chrysocoma-Felica* Shrublands included the following vegetation types:

- *Felicia-Pentzia-Chrysocoma* Shrubland (SMEC, 2010a): This shrubland community occurs on overgrazed steep, rocky, north-facing basalt slopes. The shrubland can be associated with a variety of grass species depending on grazing pressures. The shrubland occurs in the Muela site but is closely related to the *Pentzia-Chrysocoma-Felicia* Shrubland within the highland interior around Katse and Mohale. A grazing capacity of 13 ha/LSU was assigned to the vegetation type.
- Chrysocoma-Pentzia-Helichrysum Shrubland (SMEC, 2010a): This vegetation type is on overgrazed eroded mountain slopes and the vegetation is characterized by shrublands consisting of *Chrysocoma ciliata*, *Pentzia cooperi* and *Helichrysum odoratissimum*. At higher altitudes the shrubland consists of additional species such as *Helichrysum trilineatum* (Hukobetsi). A grazing capacity of 15 ha/LSU was assigned to the vegetation type.
- *Passerina-Chrysocoma* Heathland (SMEC, 2010a): The *Passerina-Chrysocoma* Heathland, although not present in the pilot sites is a dominant vegetation type to the west and south-west of Mohale Dam. A good example of this veld type occurs within the Mohale Reservoir Catchment on the road to Thaba-Tseka.
- Short Shrubland-Helichrysum (<1.5m) (SMEC, 2010a): Shrubland associated with cold, south-facing, high altitude mountain slopes degraded due to long-term overgrazing. Dominant shrubs include *Helichrysum trilineatum* and *Helichrysum witbergense*.

**Alpine Grassland**

- Alpine Grassland (SMEC, 2010a): Alpine grassland is regarded in this study as the total absence of sub-tropical grass species such as *Themeda triandra*, *Eragrostis* species and *Aristida* species. This is only so on the summit plateau above 2900 - 3000 m. The only example of this in the pilot sites is at Muela. A grazing capacity of 10 ha/LSU was assigned.

***Hyparrenhia* Grasslands**

Hyparrenhia Grasslands included the following vegetation types:

- *Hyparrhenia-Andropogon* Tall Grassland (SMEC, 2010a): The *Hyparrhenia-Andropogon* Tall Grassland is associated with warm dry northern slopes. It seems to occur mostly on dolerite-derived soils or where there is influence of dolerite. It therefore mostly occurs on lower altitudes such as river valley slopes and on the transition between sandstone and basalt, where dolerite intrusions are most common. Common grass species are *Hyparrhenia hirta* (Mohlomo) and *Andropogon ravus*. The best example of this vegetation type is at the Muela pilot site, although very little remains as most has been degraded to a *Hyparrhenia-Felicia* Degraded Grassland. An overall grazing capacity of 10 ha/LSU was assumed for the vegetation type.

- <u>*Hyparrhenia-Felicia* Degraded/Eroded Grassland</u> (SMEC, 2010a): This is the degraded form of the *Hyparrhenia-Andropogon* Tall Grassland. *Hyparrhenia hirta* and/or *Andropogon ravus* remains a common component although grasses indicative of overgrazing such as *Aristida junciformis* (Lefielo) and *Catalepis gracilis* are widespread together with the shrublet *Felicia filifolia* (Sehalahala). A grazing capacity of 11 ha/LSU was assigned to the vegetation type.

**<u>Figure 2.1.4:</u>** *Hyparrenhia* Grasslands

**Rocklands/Rocksheets**

Rocklands/Rocksheets included the following vegetation types:

- <u>*Cymbopogon-Felicia* Rock Terraces/Rocklands</u> (SMEC, 2010a): Vegetation among rock outcrops/rock terraces on steep canyon slopes at lower altitudes is characterized by *Cymbopogon pospischilii* (Lebata) and *Felicia filifolia* (Sehalahala). The vegetation type generally occurs as narrow bands within the landscape. Vegetation near rock outcrops at higher altitudes is characterized by the dominance of *Merxmuellera* species, *Erica* species and *Helichrysum* shrublets. A general grazing capacity of 27 ha/LSU was assigned to the vegetation type.
- <u>Rocksheet Vegetation</u> (SMEC, 2010a): Exposed rocksheets are a common habitat on steep north-facing slopes. In Muela, vegetation on rocksheets is dominated by the grasses *Catalepis gracilis*, *Andropogon ravus* and *Aristida junciformis*. The geophytes *Galtonia* spp and *Xerophyta viscosa* are also common components below the rocksheet. Within both the Mohale and Katse catchments, steep rocksheets are frequently shrubby. The dominant grasses are *Catalepis gracilis, Aristida diffusa/A. junciformis*, *Polevansia rigida Digitaria eriantha* and *Cymbopogon pospischilii* (Lebata); shrubs include *Pentzia cooperi* (Lebaila), *Felicia filifolia* (Sehalahala) and *Senecio* species and *Melolobium microphyllum.* A grazing capacity of 27 ha/LSU was assigned to rocksheet vegetation.

- Sandstone Grassland (SMEC, 2010a): This is a sparsely covered grassland mostly occurring on exposed sandstone. The vegetation type only occurred to the extreme north around the Muela weir.

***Leucosidea*** **Shrubland**

- *Leucosidea sericea* Shrubland (SMEC, 2010a): The *Leucosidea sericea* shrubland (Cheche) is mostly limited to the Muela pilot site. It is a large evergreen shrub or small tree which is native to the Afromontane areas of Southern Africa. It is usually found growing in dense thickets at altitudes between 1,000 and 2,500 metres. It occurs as dense stands on the cooler, moister southern slopes and as open stands on some of the northern slopes. It prefers damp conditions on deep sandy or clayey and often rocky soil and occurs in open grassland, drainage lines and on wooded rocky ridges. It is accustomed to severe frosts and grows fast provided it has sufficient moisture. On the southern slopes it is frequently associated with other trees such as *Diospyros austro-africana*, *Myrsine africana* and *Euclea crispa*. Homogenous stands can probably be considered to be bush encroachment, indicative of overgrazing. A dense stand of *Leucosidea sericea* will have a considerable impact on the grazing capacity of such areas since it decreases accessibility and impacts on the grass production. The tree is, however, a valuable source of firewood and building material. The branches are used for firewood and the leaves may be crushed and used to treat eye aliments. The flowers and young shoots are browsed by cattle and goats in the spring. The grazing capacity is poor (30 ha/LSU) due to accessibility limitations.

**Figure 2.1.5:** *Leucosidea* Shrubland

***Buddleia*** **Shrubland**

- *Buddleia salviifolia* Riverine Shrubland (SMEC, 2010a): *Buddleia salviifolia* Shrubland occurs exclusively as a dominant shrub in wooded river valleys within the Muela pilot site. *Buddleja salviifolia* is a semi-evergreen bushy shrub which is moderately frost hardy and tolerant of dry soils. It is commonly found growing below 2 200m with *Buddleja loricata* (Lelora) found at altitudes above this level. This plant has an aggressive root system and helps to bind the soil thereby stabilising banks alongside dams, rivers and streams. The wood is tough and hard and used as a building material and as a fuel source. Fresh or dried leaves can be used to brew a tea or made into an infusion and applied as an eye lotion. Decoctions from the root can be used to treat coughs and colic while the flowers can be used to clean sores. This plant provides an excellent source of fodder and is utilised by both cattle and goats.

**Figure 2.1.6**: Buddleia Shrubland

**Trees (Poplar)**

- Very few indigenous tree species occur within the grasslands of the Lesotho Highlands. Trees that do occur are largely invasive species planted by the communities, which largely include poplars (*Populus spp*.), and to a lesser extent Gum trees (*Eucalyptus spp*.) and Pine trees (*Pinus spp*.). There is also some Wattle (*Acacia mearnsii*) in the lower lying areas of the Muela pilot site.

**Figure 2.1.7**: Trees

**Settlement & Infrastructure**

- Settlements, roads, roadside vegetation and LHDA infrastructure were included in this land cover class. Although there are a number of sub-villages within each of the pilot sites, only two villages were selected for community engagement purposes. These villages included:
    - Muela
        - Muela
        - Boinyatso
    - Setibi
        - Lejone
        - Ha-Poli
    - Sepinare
        - Sepinare
        - Kosetabole
    - Koporale
        - Ha-Tsiu
        - Ha-Koporale

**Figure 2.1.8**: Settlement and Infrastructure

**Streambank Vegetation (Salix)**

- While streambank vegetation may naturally be very similar to that found in wetlands, a large proportion of the streams throughout the pilot sites, particularly in the vicinity of the villages, have Willow trees (*Salix spp*.) planted along the banks. These trees are an important fuel source and building material for the communities.

**Figure 2.1.9**: Streambank Vegetation

**Wetlands**

- Wetlands (SMEC, 2010b): Vegetation in wetlands and seepage spots within the Mohale and Katse catchments is highly diverse and can vary from pure grasslands dominated by *Merxmuellera macowanii* (Moseha), *Fingerhuthia sesleriiformis* (Thitapoho ekgolo) or *Eragrostis planiculmis* to vegetation consisting of *Kniphofia* species. The grazing capacity of *Mermuellera macowanii* seeps is poor (40 ha/LSU), however, wetlands with more palatable grass species were assigned a grazing capacity of 6ha/LSU.

**<u>Figure 2.1.10:</u>** Wetlands

**Cultivation**

- Cultivated areas included all of the segments of land utilized for cropping. Terraces between cultivated fields were included under this land cover class. The majority of these areas are concentrated around the villages, at low altitudes. However, fields also occur on some steep slopes at higher altitudes. Almost all arable land within the pilot sites is under cultivation.

**<u>Figure 2.1.11:</u>** Cultivated lands

#### *2.1.1.3 <u>Linking functional cover classes to ecosystem services</u>*

An ecosystem is a community of animals and plants interacting with one another and with their physical environment. Ecosystems include physical and chemical components, such as soils, water, and nutrients that support the organisms living within them. These organisms may range from large animals and plants to microscopic bacteria. Ecosystems include the interactions among all organisms in a given habitat. Humans are part of ecosystems. The health and wellbeing of human populations depends upon the services provided by ecosystems and their components, i.e. organisms, soil, water, and nutrients. Therefore, ecosystem services can best be described as the benefits humans obtain from ecosystems (Millennium Ecosystem Assessment, 2005).

According to the Millennium Ecosystem Assessment (2005), ecosystem services are categorised according to their functional groupings, which include provisioning, regulating, cultural and supporting services.

**Provisioning Services**

These are the products obtained from ecosystems. Examples include (Millennium Ecosystem Assessment, 2005):

- Food and fibre, which includes the vast range of food products derived from plants, animals, and microbes, as well as materials such as wood and the many other products derived from ecosystems.
- Fuel, such as wood, dung, and other biological materials, which serve as sources of energy.

**Regulating Services**

These are the benefits obtained from the regulation of ecosystem processes. Examples include (Millennium Ecosystem Assessment, 2005):

- Air quality maintenance. Ecosystems both contribute chemicals to and extract chemicals from the atmosphere, influencing many aspects of air quality.
- Water regulation. The timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes in land cover, including, in particular, alterations that change the water storage potential of the system, such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.
- Erosion control. Vegetative cover plays an important role in soil retention and the prevention of landslides.

**Cultural Services**

These are the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences (Millennium Ecosystem Assessment, 2005). Examples include:

- Spiritual and religious values. Many religions attach spiritual and religious values to ecosystems or their components.
- Recreation and ecotourism. People often choose where to spend their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area.
- Knowledge systems (traditional and formal). Ecosystems influence the types of knowledge systems developed by different cultures.

**Supporting Services**

According to the Millennium Ecosystem Assessment (2005), supporting services are those that are necessary for the production of all other ecosystem services. They differ from provisioning, regulating, and cultural services in that their impacts on people are either indirect or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts on people. Examples of supporting services include:

- Primary production,
- Production of atmospheric oxygen,
- Soil formation and retention,
- Nutrient cycling,
- Water cycling, and
- Provisioning of habitat.

The grouping of the vegetation types identified in the ICM project (SMEC, 2010) into vegetation communities (i.e. functional cover classes) allowed ecosystems supplying similar services to be grouped together. The vegetation communities were grouped according to their species composition, with a specific focus on dominant species. The categories of ecosystem services are summarized in Figure 2.1.12, and examples are illustrated in Figure 2.1.13.

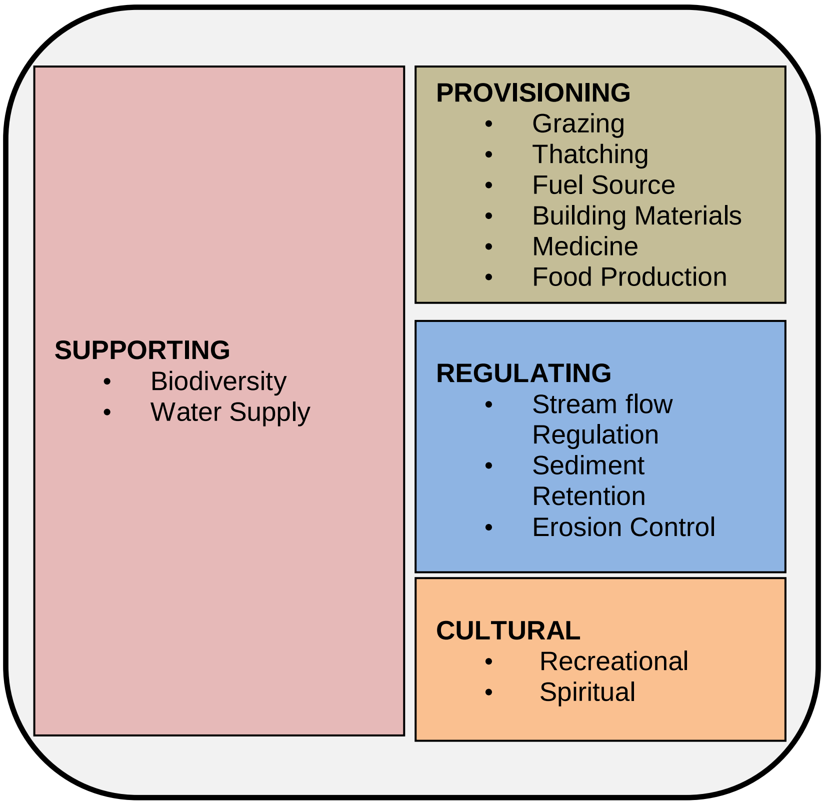



**Figure 2.1.12**: Key ecosystem services identified for the four pilot sites

| | | | |
|---|---|---|---|
| **PROVISIONING SERVICES** | **Grazing** |  |  |

| | | | |
|---|---|---|---|
| | **Thatching** |  |  |
| | **Fuel source** |  |  |
| | **Building materials** |  |  |
| | **Medicine** |  |  |
| | **Food production** |  |  |

<table>
<tr><td rowspan="4">SUPPORTING & REGULATING SERVICES</td><td>Biodiversity</td><td></td><td></td></tr>
<tr><td>Erosion control</td><td></td><td></td></tr>
<tr><td>Sediment retention</td><td></td><td></td></tr>
<tr><td>Water supply</td><td></td><td></td></tr>
</table>

| | | | |
|---|---|---|---|
| | **Streamflow Regulation** |  |  |
| **CULTURAL SERVICES** | **Recreational** |  |  |
| | **Spiritual** |  |  |

**<u>Figure 2.1.13:</u>** Illustrations of key ecosystem services identified for the four pilot sites

The scoring of the ecosystem services identified for the functional cover classes was undertaken using an ecosystem service matrix, where the size and the condition of the vegetation community, and the relative range of species within the communities that provide a service, were taken into consideration. For the purpose of assessing the impact of climate change, which will likely have the same effect at all of the pilot sites, combined ecosystem services (i.e. ecosystem services supplied at all of the pilot sites) were assessed. If present, the ecosystem services were scored either a low, moderate (mod) or high score. The scores for ecosystem services provided by the functional cover classes throughout all of the four pilot sites are provide in Table 2.1.2 below.

**Table 2.1.2**: Ecosystem scores for functional cover classes throughout all of the pilot sites

| Current Ecosystem Services Supplied by the Vegetation Communities and Land Cover Classes throughout the Pilot Sites | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Provisioning Services | | | | | | Supporting & Regulating Services | | | | | Cultural Services | |
| Vegetation Communities / Land Cover Types | Grazing | Thatching | Fuel resources | Building materials | Medicine | Food production | Biodiversity | Erosion control | Sediment retention | Water supply | Streamflow Regulation | Recreational | Spiritual |
| ***Grasslands*** | | | | | | | | | | | | | |
| *Themeda-Festuca* Grasslands | High | Low | None | None | Mod | Low | High | High | Mod | High | Mod | Mod | None |
| *Harpochloa* Grasslands | Mod | None | None | None | Mod | Low | Mod | High | Mod | High | Mod | Mod | None |
| Alpine Grassland | High | None | None | None | High | None | High | High | Mod | High | High | None | High |
| *Aristida-Eragrostis-Artemisia* Degraded Grasslands | Low | High | High | None | Low | None | Low | Low | Low | Low | Low | Mod | None |
| *Hyparrenhia* Grasslands | Mod | High | None | None | None | None | Low | Mod | Mod | Mod | Mod | Mod | None |
| ***Shrublands*** | | | | | | | | | | | | | |
| *Leucosidea* Shrubland | None | None | High | High | Mod | Low | Mod | High | Mod | None | None | Low | None |
| *Buddleia* Riverine Shrubland | None | None | High | High | Mod | Low | Mod | High | Mod | None | None | Low | Mod |
| *Felicia – Chrysocoma* Shrublands | None | None | High | None | Mod | None | Low | Mod | Low | None | None | Low | None |
| ***Wetlands*** | | | | | | | | | | | | | |
| Wetlands | High | High | None | None | High | Low | High | High | High | High | High | Mod | None |
| ***Croplands*** | | | | | | | | | | | | | |
| Cultivated areas | Low | Low | Low | None | None | High | None | None | None | None | None | None | None |
| ***Other*** | | | | | | | | | | | | | |
| Streambank Vegetation (*Salix spp.*) | Mod | None | Mod | Mod | Mod | Low | Mod | High | Mod | High | Mod | High | Mod |
| Trees (Poplar) | None | None | High | High | Mod | None | Low | Mod | Low | None | None | Low | None |
| Rocklands/Rocksheets | None | None | None | None | Low | None | Low | Low | None | None | None | Low | None |
| Settlement & Infrastructure | Mod | Low | Low | None | Low | Mod | None | None | None | None | None | High | None |

## Approach to determining the impacts of the scenarios on ecosystem services

### *2.1.1.4 Scoring ecosystem services*

The 14 functional cover classes identified above were used as the basis for determining the potential impacts of each of the scenarios on ecosystem services (Table 2.1.3). In order to identify the likely future changes in ecosystem services, an ecosystem services score for both provisioning and regulating and supporting services was derived for current conditions using an ecosystem services matrix. This approach for determining ecosystem services scores was adapted from Mander (2010).

An ecosystem services matrix was drafted for each of the four pilot sites which linked each cover class to the supply of selected ecosystem services. The level of service provided by each cover class under pristine conditions was scored from 0 to 3. Those services which scored 0 indicated that this service was not supplied by a particular cover class or was supplied at very low level while those services which scored 3 indicated that a high level of service was supplied by the cover class in question. The scores for each of the provisioning services for each cover class were summed to provide an estimate of the likely overall supply of provisioning services from a particular cover class under pristine conditions. The same approach was followed for regulating and supporting services.

**Table 2.1.3:** Using functional cover classes as the basis for determining the potential impacts of each of the scenarios on ecosystem services

| Land cover categories | Ecosystem services | | | | | | | | | | | | | Supply scores (excluding overall functionality) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Provisioning | | | | | | Regulating & Supporting | | | | | Cultural | | | | |
| | Grazing | Thatching | Feul resources | Buidling materials | Medicine | Food production | Biodiversity | Erosion control | Sediment retention | Water supply | Streamflow regulation | Recreational | Spiritual | Provisioning | Regulating & Supporting | Cultural |
| Alpine grasslands | 3 | 0 | 0 | 0 | 3 | 0 | 3 | 3 | 2 | 3 | 3 | 0 | 3 | 6 | 14 | 3 |
| *Aristida-Eragrostis-Artemesia* degraded grasslands | 1 | 3 | 3 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 0 | 8 | 5 | 2 |
| *Buddleja* shrubland | 0 | 0 | 3 | 3 | 2 | 1 | 2 | 3 | 2 | 0 | 0 | 1 | 2 | 9 | 7 | 3 |
| *Chrysocoma-Felica* shrubland | 0 | 0 | 3 | 0 | 2 | 0 | 1 | 2 | 1 | 0 | 0 | 1 | 0 | 5 | 4 | 1 |
| Cultivation | 1 | 1 | 1 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 |
| *Harpochloa falx* grasslands | 2 | 0 | 0 | 0 | 2 | 1 | 2 | 3 | 2 | 3 | 2 | 2 | 0 | 5 | 12 | 2 |
| *Hyparrenhia* grasslands | 2 | 3 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 0 | 5 | 9 | 2 |
| *Leucosidea* shrubland | 0 | 0 | 3 | 3 | 2 | 1 | 2 | 3 | 2 | 0 | 0 | 1 | 0 | 9 | 7 | 1 |
| Rocklands/Rocksheets | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 1 |
| Settlement and infrastructure | 1 | 1 | 1 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 6 | 0 | 3 |
| Streambank vegetation | 2 | 0 | 2 | 2 | 2 | 1 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 9 | 12 | 5 |
| *Themeda-Festuca* grasslands | 3 | 1 | 0 | 0 | 2 | 1 | 3 | 3 | 2 | 3 | 2 | 2 | 0 | 7 | 13 | 2 |
| Trees | 0 | 0 | 3 | 3 | 2 | 0 | 1 | 2 | 1 | 0 | 0 | 1 | 0 | 8 | 4 | 1 |
| Wetlands | 3 | 3 | 0 | 0 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 2 | 0 | 10 | 15 | 2 |

The size and condition of each of the cover classes also plays a critical role in the supply of ecosystem services. For example, a large area of grassland is likely to provide more services than a smaller area. In addition, an intact pristine grassland is also likely to provide a greater quantity of services than a degraded grassland. In the current study, the size of each of the cover classes was based on the vegetation mapping undertaken in the ICM study and was determined using GIS. A size category was then assigned to the area of each cover class using the scoring system below:

| Area in hectares | Size category |
|---|---|
| 0 | 0 |
| 0.5 | 0.5 |
| 25 | 1 |
| 75 | 1.5 |
| 100 | 2 |
| 150 | 1.5 |
| 200 | 3 |
| 250 | 3.5 |
| 300 | 4 |
| 350 | 4.5 |
| >350 | 5 |

The condition of each of the cover classes was determined using expert judgment. The following scoring system was applied:

| Level of degradation | Condition score |
|---|---|
| Not present | 0 |
| Severely degraded | 1 |
| Moderately degraded | 2 |
| Average condition | 3 |
| Good condition | 4 |
| Pristine | 5 |

The condition score and size category were combined to provide an overall functionality score for each cover class. The functionality score for each cover class was then multiplied by the summed scores for provisioning services and regulating and supporting services as determined above. This resulted in an overall supply score for provisioning services and regulating and supporting services for each cover class under current conditions.

Although scores for cultural services were derived using the same process, these scores have not been included in the assessment as there is very little available information of the utilization of the cover classes for cultural or recreational activities. As a result, the confidence in these scores is very low.

#### ***2.1.1.5 Understanding historic changes in land use***

One of the greatest threats to biodiversity and ecosystem functioning is land transformation. Such change may be the result of a variety of drivers and pressures such as poor agricultural practices, lack of effective governance, market forces and urban expansion.

To determine changes that have already taken place at each of the pilot sites, a comparison was undertaken using aerial photography taken in 2001 and 2010. The 2001 imagery was used by SMEC to map vegetation communities as part of the ICM Project. 2010 is the most current available photography for the majority of the study areas. Unfortunately, no recent imagery was available for the Ha Koporale site and consequently, the analysis of potential future changes in ecosystem services at this pilot site relied on the extrapolation of results from the other study areas.

Cultivated areas identified by SMEC on the 2001 imagery were overlaid on the 2010 imagery and areas cultivated subsequent to 2001 were mapped for each pilot site (Figure 2.1.14).


**Figure 2.1.14:** Use of imagery to identify and map areas cultivated subsequent to 2001 SMEC Project

An analysis of the cultivated areas in relation to land capability classes was also undertaken. Land capability is determined by the collective effects of soil, terrain and climate factors and provides an indication of the long-term use of land and the permanent limitations associated with the different land use classes. Classes I and II indicate high potential arable land with few limitations while Classes III and IV are suitable for crop production but have moderate to severe limitations (Figure 2.1.15). Classes V, VI and VII are suitable for grazing and forestry while Class VIII is only considered suitable for wildlife.

| **Land Capability** | | | **Intensity of use for rain-fed agriculture** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Orders** | | **Classes** | **Wildlife** | **Grazing & Forestry** | | | | **Crop Production** | | | |
| | | | | Forestry | Veld | Veld reinforce-ment | Pastures | Limited | Moderate | Intensive | Very Intensive |
| **Arable** | **A** | I | | | | | | | | | |
| | | II | | | | | | | | | |
| | **B** | III | | | | | | | | | |
| | | IV | | | | | | | | | |
| **Non arable** | **C** | V | | | | | | | | | |
| | | VI | | | | | | | | | |
| | | VII | | | | | | | | | |
| | **D** | VIII | | | | | | | | | |

**Figure 2.1.15:** Overview of land capability classes

Land capability classes were delineated by SMEC for each of the pilot sites as part of the ICM Project. This information was used in the current study. For each capability class, the area of land already under cultivation in 2001 was calculated as a percentage of the overall land available within each land capability class. Not surprisingly, large tracts of high production areas (i.e. Classes I and II) had already been cultivated in 2001 while limited cultivation had occurred in marginal areas (Class VII and VIII) (Figure 2.1.16). This trend is evident across all three pilot sites.

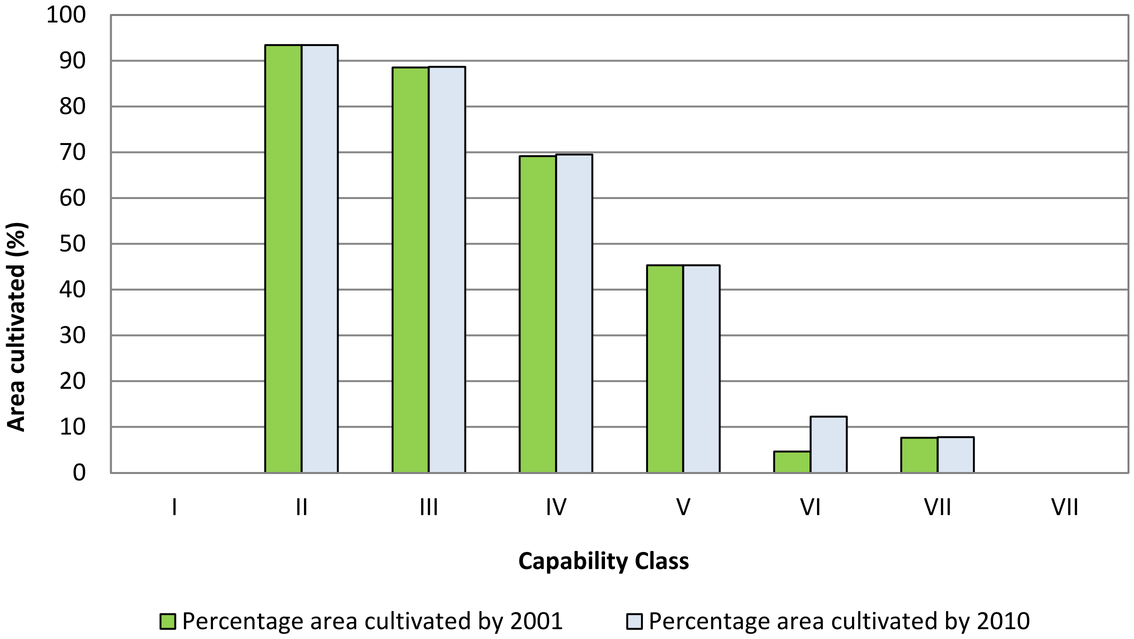



**Figure 2.1.16:** Trend in cultivation of land within each land capability class at Setibi

### *2.1.1.6 Projecting changes in land use and ecosystem services for each of the scenarios*

This trend in utilizing land which is most suitable for cropping first is likely to continue into the future. As a result, those functional cover classes and associated ecosystem services, which occur in these higher production areas, are most threatened and likely to be lost first unless measures are introduced to control or manage this utilization.

Based on this assumption, the relative contribution of the area of each capability class within each vegetation community was calculated. These percentages were then used to determine the relative contribution of the area of each vegetation community in each land capability class to the overall provisioning and regulating and supporting services score. The number of capability classes and associated area likely to be utilized for cultivation under each scenario was then estimated. Based on this utilization, the relative loss of ecosystem services was then determined by adjusting the ecosystem services scores accordingly. In addition, the condition scores were revised based on the projected impacts of the scenarios. This resulted in either a reduction or an improvement in the provisioning, regulating and supporting scores from baseline conditions. These scores were then graphed to provide an indication of the likely changes in ecosystem services as different capability classes are utilized under each scenario (Appendix E).

The contribution of each vegetation community to the individual ecosystem services was also determined. These calculations assumed a direct relationship between the size of an area and the level of service supplied. The score for each ecosystem service was therefore multiplied by the area available under both baseline conditions (2010) and the likely remaining area after cultivation for each scenario. These scores were then graphed. It is important to note that these scores do not take condition into consideration. They are also intended to provide an indication of likely trends and changes in ecosystem services rather than to detail an exact level of service supplied.

### Approach to identifying the combined impacts of climate change and scenarios on ecosystem services

Combining the impacts of climate change and anthropogenic activities relied on the information generated in both Sections 4 and 5. In order to determine the implications of climate change on ecosystem functioning, ideal habitats for each of the vegetation communities were identified based on relationships between altitude, aspect, slope and proximity to watercourses. These habitats provided an indication of those areas which were most suitable and therefore most likely for the selected vegetation communities to expand into. Alpine areas, shrublands, streambank vegetation (mostly *Salix* sp) and trees were expected to expand as a result of increasing levels of $CO_2$. Based on this assumption, potential distribution maps of vegetation communities under climate change were generated. These maps were then intersected with land capability classes to provide an indication of the projected area of each vegetation community within each land capability class for each site. These percentages were then used to determine the relative contribution of the area of each vegetation community (projected under climate change) in each land capability class to the overall provisioning and regulating and supporting services score.

Based on the assumption that higher production areas would be utilized first, the different scenarios relied on the utilization of different numbers of capability classes. Thus under the Rabbit scenario only capability classes I to IV were cultivated while under the Jackal scenario all capability classes were cultivated. While it is acknowledged that capability classes IV to VIII are not suitable for cultivation, it is assumed that in extenuating circumstances an attempt would be made to utilize these areas. In addition, it was assumed that the entire area of a capability class would be cultivated even though in reality this is likely to be limited by a range of other factors.

The area of each vegetation community (projected under climate change) remaining after this conversion was then calculated for each scenario. Similarly, the contribution of these remaining areas to the ecosystem services scores was then determined and graphed. The respective graphs for each site have been included under Section 6.

## 2.2 Agricultural assessment

### Methods and data sources

The approach to conducting the agricultural assessment was to review available literature and existing reports to understand the current agricultural context of the Highlands of Lesotho. This was compiled into a status quo report to provide an overview of agriculture in Lesotho.

The agricultural assessment then sought to better understand the climate change scenarios for the highland areas and interpret how the projected changes would impact on crop and livestock production systems in the Highlands. A number of key data sources were used for this, which are listed below.

- The Integrated Catchment Management Reports compiled for the Pilot Catchment Areas (SMEC, 2010a) were used to identify biophysical characteristics of the study areas. In particular, soil types and depth, fertility and land capabilities were extracted from these reports from a biophysical perspective. Some information on crop and livestock management practices was also drawn from these reports.
- The South African Atlas of Climatology and Agrohydrology (Schulze, 1997) was used to identify current climatic characteristics of the PCAs.
- The Atlas of Climate Change and the South African Agricultural Sector: A 2010 Perspective (Schulze, 2010) was used to determine the projected climate changes for the intermediate and more distant future.
- A number of field visits were conducted in August to October to meet with farmers and to view their farming and livestock management systems, to discuss how they dealt with current climatic variations and better understand vulnerabilities and opportunities for adaptation.

This information informed the development of the overview of agriculture, the effect of climate change scenarios on agriculture, the impact of the four scenarios developed in the scenario building process on agriculture and finally the effect of climate change under the four scenarios.

## Climate, soils and agriculture

Lesotho has a sub-tropical to temperate climate with warm wet summers and cold dry winters. Rainfall ranges from 500mm pa in the southern lowlands to 1000mm per annum in the north eastern Highlands and is characterised by short duration, high intensity events. Frosts are common in winter and hailstorms occur frequently. In the summer months, usually in December and January and sometimes February, hot, dry spells occur (Mosenene, 1999). Between 75% to 85% of Lesotho's rainfall occurs in the summer months (October to March) and potential evapotranspiration is higher than precipitation throughout the year. The inter-annual variability of rainfall is high, ranging from 20% to 40%.

Climate variability, characterised primarily by periods of droughts and wetter periods as well as floods, has been occurring in southern Africa since before record keeping began. For example, during the nineteenth century, large areas of southern Africa experienced eight periods of drought, alternated with six wetter phases often associated with widespread flooding (Midgley, *et al*., 2011). In Lesotho, farmers deal with inter annual and intra annual climate related stresses of drought and floods on a regular basis.

Soils in the Highlands tend to be more fertile than those in the lowlands. Few highland farmers add nutrients (manure or fertiliser) to their soils. This is attributed by Midgley *et al.,* (2011) to the fact that mountain soils are formed with a higher base saturation (neutral pH) and have a generally higher organic matter content, meaning that plant nutrients are readily available and can support subsistence levels of production. While this is true, these practices have resulted in the mining of nutrients from the mountain soils, resulting in degradation, reduced fertility and reduced yields.

The cool Lesotho climate limits the effective growing season to the months between November and March. Rainfall is the main limiting factor prior to November, and cool temperatures limit crop growth after March. This means that people in the Highlands of Lesotho have a very small window during which crops can be grown. This, compounded by generally low rainfall, erratic climate characteristics and low soil fertility all contribute to low and erratic crop yields in the Highlands.

## Crop production

Agricultural crop production in the Highlands is characterized by smallholder agriculture that is almost exclusively rainfed. All good arable land (i.e. land capability classes I to IV) around the highland villages is used for crop production.

### 2.2.1.1 Field sizes and yields

There is no specific detail on crop yields for the target PCAs, however a number of different sources report low crop yields. The Lesotho Bureau of Statistics (Lesotho Bureau of Statistics, 2009) report yields per district and do not distinguish between the Highlands and the lowlands. The Lesotho Bureau of Statistics estimated the expected yields for each district for the 2010/2011 planting season to determine production for important stable crops. This is provided in Table 2.2.1.

**Table 2.2.1:** Production of staple crops in the Districts in Lesotho

| | WHEAT | | | SORGHUM | | | MAIZE | | |
|---|---|---|---|---|---|---|---|---|---|
| **District** | **Area (ha)** | **Yield (t/ha)** | **Production (t)** | **Area (ha)** | **Yield (t/ha)** | **Production (t)** | **Area (ha)** | **Yield (t/ha)** | **Production (t)** |
| Botha Bothe | 309 | 0.65 | 201 | 1270 | 1.39 | 1769 | 5421 | 0.57 | 3090 |
| Leribe | 780 | 0.67 | 523 | 4803 | 0.96 | 4605 | 20963 | 0.69 | 14464 |
| Thaba Tseka | 1153 | 0.97 | 1118 | 852 | 0.47 | 403 | 9932 | 0.61 | 6058 |
| Berea | | | | 4507 | 1.29 | 5831 | 17972 | 2.19 | 39359 |
| Maseru | 1338 | 0.6 | 800 | 3996 | 1.12 | 4496 | 18793 | 0.71 | 13343 |
| Mafeteng | 24 | 0.15 | 4 | 4834 | 0.63 | 3066 | 19284 | 0.18 | 3471 |
| Mohale's Hoek | 1254 | 0.79 | 987 | 5005 | 0.82 | 4086 | 13877 | 0.54 | 7493 |
| Quthing | 661 | 0.52 | 343 | 3121 | 0.85 | 2640 | 4434 | 0.59 | 2616 |
| Qacha'sNek | 1192 | 0.9 | 1077 | 773 | 0.72 | 560 | 3416 | 0.49 | 1674 |
| Mokhotlong | 7619 | 0.73 | 5588 | 1341 | 0.47 | 627 | 8736 | 0.74 | 6465 |
| **LESOTHO** | **14331** | **0.74** | **10640** | **30504** | **0.92** | **28082** | **122828** | **0.8** | **98035** |

Other reporters provide similar results for maize production of 450-500kg/ha (Silici *et al.*, 2011; Mosenene, 1999; FFSA, 2004). Average yields for maize in South Africa are 2-3 tons per hectare under similar rainfall conditions, although some farmers in high rainfall areas with good soils regularly achieve more than 8 tons per hectare for maize under dryland conditions.

#### *2.2.1.2 Land holdings*

Mosenene (1999) notes that land users have limited access to land and found that most land users have access one or two fields. Often this is one field within the village area and another in the surrounding hills. The average size of fields reported by Mosenene was 1.3 ha, while the FAO (1997) reports field sizes of 0.8ha and FFSA (2004) report field sizes of 0.48ha. Midgley *et al.,* (2011) noted that in the mountains, 22% of households surveyed were landless, compared to 2% in the lowlands. Average land holdings per household were 0.72ha in the mountains and 1.43ha in the lowlands. In the survey year, drought was experienced. Only 8% of land was fallow in the Highlands, compared to 32% in the lowlands, during this drought period. This highlights the scarcity of available land for cropping in the Highlands and the vulnerability of Highland communities to drought and crop failure.

Thus normal crop land holdings by households in the Highlands can be between 0.48ha and 1.3ha.

#### *2.2.1.3 Crops and cropping systems*

Maize is a staple food for southern Africa. Maize production accounts for 58% of the cropping area in southern Africa (CEEPA, 2006) and in Lesotho, 80% of the croplands are planted to maize. This highlights the importance for maize as a staple crop, but also highlights the extreme vulnerability of farmers should the maize crop fail.

Other important staple crops are wheat, sorghum, peas and beans make up the remaining 20% of agronomic crop production. A variety of vegetables were reported to be grown by homesteads interviewed by the project team. This included green leafy vegetables, root crops and fruit bearing vegetables. Interestingly, peas are classed as agronomic crops, while potatoes are classed as vegetable crops. This categorization is based on whether or not the crop can be dried and stored for long periods of time (peas can be dried and stored, while potatoes can't be stored and dried).

Lands are traditionally prepared planted in October and November when the first rains are expected. Land is prepared using animal drawn ploughs. Oxen are often in short supply due to disease, theft and low fertility rates in livestock. As a result, fields can end up being planted late (November, December and sometimes January) which has negative implications for crop production. The other impact of this is that farmers who are borrowing animals may have to plant at a given time, regardless of whether the rains have come, as the owner will need the oxen with the onset of rains. Households do generally, however, wait for the onset of rains prior to planting.

Farmers generally do not use any inputs and use seed saved from the previous year for planting. There is some exchange of seed between farmers, but the use of improved hybrids was not reported by any of the farmers interviewed. Similarly, no other inputs such as fertilizer and pesticides were reported to be used to enhance crop production.

**Figure 2.2.1:** Oxen being used for land preparation. Note the significant size variation on the animals (the one at the back is barely a year old), highlighting the shortage of traction animals. All the oxen should be the same size as the leading animal (brindled).

Yields are declining and are estimated to be half of what they were in the 1970s and are one third of the yield those in the neighbouring Free State Province in South Africa. To maintain production, highland agriculture is increasingly encroaching onto steep slopes dominated by shallow entisols or inceptisols (young and shallow soils) (Mosenene, 1999).

#### ***2.2.1.4 Soil conservation***

The combination of soil type, slope and rainfall intensities, compounded by poor management has resulted in severely accelerated erosion in many places in Lesotho. This is demonstrated in the following statistics. There are approximately 6,863 dongas covering a land area of 60,000 ha, representing a soils loss of 0.7 million tons per annum (1998 estimate). However, dongas do not account for the major part of erosion: surface sheet erosion is estimated to lose 40 million tons of soil per annum (Government of Lesotho, 1998 cited in Pederson, 2007) Midgley *et al.,* (2011) note that only half of the communities that were surveyed by them in the Highlands made use of soil erosion control measures (primarily water diversion furrows and some terracing).

Field visits conducted by the project team revealed that most agricultural lands near the villages in the PCAs were terraced. These terraces were reportedly established in the 1960s and 1970s by government and NGO agricultural extension agencies. They have remained more or less intact, but do extend over depressions and natural waterways. As a result, gulley erosion does occur in these areas. Farmers are reluctant to convert these areas into waterways as they are the most fertile areas by virtue of their higher moisture status and deposition of fertile silt from agricultural lands into these areas. Farmers manage and shape their own terraces individually and as a result, the terracing system is also not part of an integrated and holistic soil conservation system as would be observed in a commercial farming system.

Crop lands further from the villages were generally found not to be terraced. The villagers interviewed note that this is because they were established more recently and were not part of the original soil conservation programme.

In some areas, water diversion channels were observed above agricultural lands and a few instances where stone lines had been established were also observed. These two types of soil conservation measures appear to be driven largely by the efforts of external agencies, such as LHDA and NGOs.

Soil conservation measures are adequate in that they are in place, however soil conservation design and layouts could be vastly improved. This would have positive effects in terms of reducing soil erosion, retaining moisture and enhancing crop yields.

#### *2.2.1.5 Water harvesting and conservation*

It is estimated that less than one percent of crop production in Lesotho is irrigated and almost all subsistence and smallholder agriculture is rainfed. Large irrigation schemes are expensive and may not be suitable, given the topography and geology, particularly in the Highlands (Midgley *et al.,* 2011).

Field visits to the project sites showed that at many of the villages, small scale water harvesting systems that capture and store runoff had been developed. However the systems, which had been established by 'outside' agencies working in the area, were not functioning due to lack of maintenance and broken piping.

To conserve soil moisture farmers practice (i) winter ploughing to increase the infiltration of the first rains and (ii) ridging in maize lands to retain water on the crop lands and encourage infiltration of rain water.

Small scale irrigation and water harvesting schemes are lacking, even though they are viable options for smallholders in the face of climate change.

### Livestock and grazing

The keeping of livestock is an important cultural activity and livelihood strategy for highland communities, particularly considering that 80% of Lesotho is made up of rangelands (Marake *et al.,* 1998). From a livelihood perspective, livestock are used for transport (donkeys and horses), animal traction (oxen), milk (cows) and meat. In addition to this, the selling of wool (angora goats and sheep) is an important source of income for highland communities. Finally, livestock are also traded at times when cash is needed by a household.

Small livestock (angora goats and sheep) are the most numerous of the livestock kept, as they are well adapted to the difficult highland climate and can make good use of available grazing and browsing. There are fewer cattle as they are more difficult to sustain from a grazing perspective, but are important for land preparation and milk.

Most highland communities own some livestock, although the numbers vary greatly. Many households will own less than thirty animals in total, while some individuals own herds of 300 and more animals, made up largely of small livestock. The high number of livestock in the Highlands place considerable pressure on the grazing resources of the rangelands.

#### *2.2.1.6 Grazing management and allocation*

Grazing on rangelands is managed on a "three area system", summarised as follows:

- **Area A**: Alpine summit and high lying areas within each district, which is managed communally for all villages and grazing allocations are the responsibility of the principle chief. These are the summer grazing cattle posts and largely fall outside of the PCAs.
- **Area B**: The natural rangelands on the outskirts of the villages and are normally situated in the high altitude valleys, ridges and mountains above the villages. These are generally the foothills.
- **Area C**: This is the grazing which occurs within the village and the cultivated areas and are usually the winter grazing areas. These are normally the foothills in highland villages.

Grazing allocation in the cattle post areas is under the jurisdiction of the Principal Chiefs, who allocate permits to livestock owners to graze in the mountainous cattle posts. Local chiefs (i.e. village chiefs) allocate grazing rights in the vicinity of the villages.

The main form of management of grazing is to rest an area by the Chief or Principal Chief declaring an area closed for grazing to all livestock. Individuals are charged with the duty of impounding animals that trespass on these areas (FAO, 1997). Rangeland Management Areas (RMAs) and Grazing Associations (GAs) have been established to manage grazing in the highland cattle posts with intention of enhancing the sustainable use of Lesotho's rangelands, which are heavily overgrazed.

A number of studies (e.g. FAO, 1997; Pederson, 2007) report that the rangelands are heavily overstocked and the current stocking rate cannot be sustained indefinitely. Rangelands degradation has reached a critical point and has led to the widespread replacement of palatable grasses by invaders and bush encroachment species, such as *Chrysocoma ciliata*. Annual soil loss from Rangelands is estimated at 23.4 million tons per year. Frequent droughts also exacerbate this situation (Marake *et al.*, 1998) and estimates of overstocking range between 50 and 300 percent (FAO, 1997).

This trend of widespread rangeland degradation is reflected in the PCAs. SMEC (2010a) conducted an assessment of grazing land condition in the PCAs and found the following levels of degradation:

- **Muela**: At least 21% severely degraded or overgrazed; 19% is low to moderate potential and 9% can be regarded as high potential grazing. The potential for livestock breeding is significantly limited to the degraded state of the veld and the high coverage of shrubs. The high coverage of shrubs could not be attributed to bush encroachment as no historical information was available

- **Setibi**: At least 26% severely degraded; 37% has been transformed; 13% low to moderate potential and 24% high potential grazing.
- **Sepinare**: At least 30% of the grazing land has been severely degraded. About 37% has been transformed, 16% is of low to moderate potential and 17% can be regarded as high potential grazing.
- **Ha Koporale**: At least 24% has been severely degraded; 25% transformed; 34% low to moderate potential; 16% high potential

Grazing capacity in the PCAs was calculated to be between 5 and 41 hectares per Large Stock Unit (LSU). The calculation of actual stocking rates is fraught with difficulty as livestock regular move in and out of the PCAs, and the cattle post areas are well beyond the boundaries of the PCAs. Nevertheless, site visits and field observations by the project team bear out SMEC's and others' observations that grazing is extremely limited, basal cover is poor and the rangelands are heavily overgrazed.

Despite the presence of grazing management plans and grazing associations, the systems are poorly enforced. A number of observations were made of small livestock being kept in the highland cattle post areas throughout winter. This is because there is simply no grazing available in the lower lying areas adjacent to the villages.

While rotational grazing and veld resting is theoretically practiced, in reality, there appears to be little control over livestock numbers or their movement by the principal chiefs, the grazing associations and other agencies responsible for rangeland management. A record is kept of livestock numbers by the principal and local chiefs, but these are not linked to stocking rates or any other grazing management programme or system.

## Discussion

Agriculture's contribution to Lesotho's gross domestic product was 50% in the 1970s. During this time, livestock contributions dominated, contributing 60% while cropping contributed 40% to GDP. The GDP contribution of agricultural is now estimated to be between 12 and 14% in the 1990s and has declined further since then (Mosenene, 1999; Ziervogel and Calder, 2003). Mosenene (1999) also reports declining state investment in agriculture (30% of public resources down to 8%) and the agricultural sector now relies heavily on foreign donor aid. This has certainly contributed to declining agricultural production in Lesotho.

This decline in agricultural production in Lesotho is reflected starkly in the incidences of malnutrition in the country. According to the World Food Programme (2010) 42% of children under the age of five are considered to have stunted growth, and 22% of child deaths are attributed to malnutrition. Low household food security is a common in Lesotho, with the worst months being those just prior to the maize harvest (January to March). A household survey conducted in an FAO (1997) study found that most households (72%) were food self-sufficient for only eight months. These figures highlight the precarious state of food self-sufficiency and the potentially devastating effect the late onset of the rainy season can have on food production.

Animal production in the Highlands is also poor. Herds and flocks are typically in poor condition with low fertility rates and the quality of animal products (especially wool) is poor. This is largely due to the lack of adequate grazing resources, but poor genetic stock also contributes to this. Rangeland management systems and enforcement is poor and overstocking is the norm. As a result rangeland resources are extremely degraded.

For cropping, there is a general decline in production which can be attributed to a decrease in soil fertility, an absence of crop inputs compounded by declining state investment in agriculture.

## 2.3 Social assessment

### Methods and data sources

**A: Literature Review**: was undertaken to elicit information from existing literature on the socio-economic context in the Lesotho Highlands. Among other aspects, the literature review informed conclusions on the following:

- Population dynamics
- Employment and poverty levels
- Household characteristics- including household size and composition
- Livelihood strategies
- Traditions, cultures, beliefs and value systems
- Access to land and security of tenure
- Access to infrastructure and services
- Governance and Institutional arrangements

Various data sources were used, ranging from reports and government documents to Internet sources. The key sources of data included:

- **Lesotho Bureau of Statistics (LBoS)**: provided statistics on population dynamics, education levels, age and gender profiles and poverty levels. LBoS data was largely available at National and District rather than village level. LBoS was set up by the Ministry of Finance and Economic Development (www.bos.gov.ls). LBoS is a national hub of official statistics on economic, social, and demographics in relation to the development needs of Lesotho. The statistics are used for social and economic planning, research and public information.

- **SMEC International Reports**: provided key information and statistics pertaining to the project sites. SMEC International was contracted by The Lesotho Highlands Development Authority (LHDA) to implement the Integrated Catchment Management (ICM) programme in the Lesotho Highlands Water Project phase 1 areas, namely, Muela, Kosetabole-Sepinare (Katse), Setibi-Mamohau (Katse) and Koporale-Ts'iu (Mohale) sub-catchments. A series of reports were produced from the initiative and provided valuable baseline information for this Project.

- **Lesotho Meteorological Services (LMS) Reports**: provided key statistical information on population in the Highlands. The Lesotho Meteorological Services is primarily responsible to collecting and sharing weather and climate information, e.g. temperature, frost and timing of frost droughts, floods, storms, hail, winds, and snowfall.

- The internet and websites such as **World Bank** on development indicators (www.worldbank.org) provided statistics on indicators such as education, poverty and health levels in Lesotho.

**B: Vulnerability Assessment**: was undertaken by the Project Team at the eight villages to solicit the perceptions of the people at the villages on the nature and extent of household vulnerability at the project sites. The vulnerability assessment was structured into (a) a household questionnaire survey and (b) focus group discussions.

***(i)*** ***A household questionnaire survey*** was undertaken with a sample of eight households per village. It was used to collect information on:
- Household demographics
- Household's socio-economic status
- Perceptions on underlying causes of vulnerability

***(ii)*** ***Focus groups discussions***, with herd-boys, older men (traditional men) and groups of men and women, were used to solicit people's perceptions on the following issues:
- Major effects brought by climate change
- Land degradation and livelihood vulnerability
- Sustainable management of natural resources, e.g. wetlands
- Underlying causes of vulnerability
- Assets and strategies to mitigate livelihood vulnerability

**C: Interviews with leadership structures, local households and livestock owners**

***(i)*** ***Institutional/governance structures***: meetings were held and interviews were conducted with local institutions and leadership structures to introduce the project and to get buy-in from the leadership. Local structures such as the Traditional Leadership (Chiefs), Community Councils, the Katse Catchment Liaison Forum (which includes Principal Chiefs, District Administrator, Heads of Departments, Community Councils and LHDA) were engaged in the early stages of the project. The following issues were discussed:
- Access to land, tenure
- Livestock control
- General community development issues

***(ii)*** ***Local households***: meetings were held with local households to introduce the project, create awareness, initiate dialogue, and to elicit ideas from local people regarding project implementation. In addition, households were key in the Project Team's understanding of:
- Access to land and security of tenure, social and welfare support programme
- Various livelihood strategies, including crop production and livestock practices.

***(iii) Livestock farmers*:** interviews were conducted with livestock farmers to gather information on a range of livestock aspects including:

- Types of livestock that households keep
- Sizes of the different livestock types
- Uses and benefits of different livestock types
- Grazing arrangements, including rules and regulations, institutions responsible for allocating grazing land and controlling or managing grazing areas

A number of challenges were experienced during the data collection process. These included:

- Little information was available at village level
- Some data were available at District level but not consistently across all Districts into which the Project's pilot sites fall.
- Some important statistics, e.g. household sizes, population sizes, etc. were only available largely at national level.
- Inconsistences in data reported, e.g. population figures from a similar period varied from one data source to another.

Nevertheless, the available data provided a good platform for identifying risks and vulnerabilities to climate change that can inform important adaptation strategies.

## Livelihood vulnerabilities and baseline context

An assessment of the existing livelihood vulnerabilities provides important insights into the nature and extent of livelihood vulnerabilities to which households are exposed. The understanding of the vulnerability context allows for informed planning and adaptation, in order to minimize the risks and vulnerability to external shocks while improving the resilience of livelihoods and their well-being. The vulnerability context of the project sites was informed by the literature review, interviews and the Vulnerability Assessment that was undertaken by the Project Team. The vulnerability context is summarized below. However, for a detailed analysis of the vulnerability context, refer to the report on 'The Socio- Economic Context and Key Vulnerabilities to Livelihood Strategies in the Lesotho Highlands'[1]

***a) Unemployment and lack of income generating activities***

Economic activity plays an important role in alleviating vulnerability and building resilience levels of households. Income generating activities also provide households with an opportunity to apply their entrepreneurial skills and traditional knowledge (van Niekerk and van Niekerk, 2009). Unemployment and lack of income generating activities limit opportunities that can contribute to improving people's well-being, i.e. income generating reduce poverty and add to the 'feeling' of well-being. Households at the pilot sites consider unemployment as a key driver of vulnerability. High unemployment levels mean that households struggle to find opportunities to earn incomes. These incomes are important for buying necessities that households are not able to produce themselves. This means that households are highly dependent and have to rely

[1] A separate report documenting the Socio-economic Context and Key Vulnerabilities to Livelihood Strategies in the Lesotho Highlands has been produced. A detailed analysis of the key drivers of vulnerability has been undertaken in this report.

heavily on what they produce for themselves without a backup of financial resources to form a safety net in the event of crop failures or other disasters. By improving household's financial capital, which impacts on food security, income generating activities can improve the overall livelihood status of a household.

A high percentage of households in the villages of Boinyatso and Ha-Kosetabole in particular attribute vulnerability to unemployment in particular.

***b) Limited access to land for cultivation***

Access to sufficient productive land is critical for rural households' livelihoods. It minimizes vulnerability to hunger and poverty, by influencing their capacity to invest thereby enhancing their livelihood prospects (IFAD, 2008). Therefore, lack or limited access to land for cultivation exposes households to food insecurity. It limits a household's ability to meet its food needs and increases reliance on already scarce cash incomes to purchase food to supplement what the household is able to produce for itself. Midgley *et al*., (2011) noted that in the mountain Districts, 22% of households surveyed were landless (compared to 2% in the lowlands). Average land holdings per household were 0.72ha and, in the survey year, 8% of the fields were left fallow.

Estimates are that an average field of 0.72 ha produces about 360 kg of maize per year (FAO, 2010). This translates to about seven 50kg bags of maize yielded per 0.72 ha resulting in an annual yield of 0.36 tons of maize per annum per household. Assuming an overage of 5.42 people per household (LBoS, 2006), 0.72 ha will be able to supply about 179g of maize per person per day. A study undertaken in Malawi reported that 470g of maize is required to satisfy the energy daily requirements of an adult that relies on maize for their staple meals (Sahley, *et al.*, 2005). It can therefore be concluded that many households in the Highlands are currently unable to meet their much needed daily energy requirements. The household vulnerability assessment in the pilot site areas revealed that households in Ha-Ts'iu and Boinyatso did not associate vulnerability with access to land, a high percentage of the households in Muela, considered the lack of access to enough land for cultivation as a key driver of vulnerability.

***c) Deteriorating rangelands condition***

Rangelands are the basis for livestock production in the Highlands. The amount and quality of grazing is a strong determinant of the number of livestock that can be sustained on the rangelands. The quality of animals also depends on the condition and quality of the rangelands. Owing to poor rangelands condition, livestock body condition, productivity and value can depreciate. Some households felt that the deteriorating condition of the rangelands is affecting the condition of their livestock, and the resilience of livestock to survive extreme events such as droughts and cold spells. This puts the households at risk of stock losses during extreme events in particular, exposing the households to a loss of highly valuable livestock assets, which would negatively affect the households' livelihood. However while deteriorating rangeland condition was acknowledged by households in most (five out of eight) of the pilot site areas, it was not recognized as a major driver of vulnerability for local households, and was not recognized at all at three of the sites (Ha-Ts'iu, Muela and Ha-Sepinare).

**Figure 2.3.1**: Households' livelihood strategies founded primarily on primary production and resource harvesting

***d) Variable weather and climatic conditions***

Rural livelihoods are fundamentally linked to both short term (weather) and long term (climatic) changes. Households in the Highlands rely on rain-fed agriculture to sustain their livelihoods. Weather (and rainfall in particular) is also an important driver of rangeland condition. Unfavourable and variable weather and climatic conditions, such as droughts, floods and snow therefore have a strong influence on the vulnerability of households. This was very widely recognised by households across all eight of the pilot sites. Households listed increasing frequency of droughts, unseasonal and erratic rainfall as examples of variable weather and climatic conditions as examples of variable weather and climatic conditions, which they say undermines their ability to meet their livelihood needs and increases vulnerability levels.

***e) Poor crop yields***

The livelihoods of the households in the Highlands depend primarily on crop production. Maize is planted as the main staple crop, and is essential for food security. Households directly consume most of their own maize produced. However, households at the project sites reported declining yields. Low or poor yields therefore compromises households' ability to meet their own maize requirements and requires that they spend scarce cash resources on buying this staple crop. Declining crop yields was widely reported across all pilot sites as a key driver of vulnerability. A decline in crop yields, particularly for the staple crops, induces food insecurity and undermines the resilience of household livelihoods and well-being.

***f) Lack of markets for goods produced***

Households cultivate a range of crops that, while primarily for domestic consumption, can be sold to supplement cash incomes. Access to markets determines livelihood options and choices. Lack of market opportunities, undermines these options and choice. Vegetable crops for example are sometimes sold in small quantities to other local households to generate cash income. However due to limited disposable cash incomes in the Highlands, the local market is small which means that these opportunities are very limited. Distance to markets in larger centres such as Maseru makes them inaccessible or unfeasible under current economic, production and infrastructure conditions. Currently, production yields in the Highlands are low, and therefore not viable to allow households to enter into the commercial markets. Not all villages consider lack of access to markets as a driver of vulnerability.

***g) Limited household assets base***

People and their access to assets are at the centre of livelihoods approaches (www.dfid.org.uk). Households' livelihood assets can be clustered into five groups (FAO, undated; www.dfid.org.uk; www.ifad.org):

- Physical Capital, e.g. infrastructure such as road and hospitals
- Social Capital, e.g. social networks, traditions and beliefs
- Financial Capital, e.g. credit support and availability
- Natural Capital, e.g. land, water and fuel wood
- Human Capital, e.g. skills and health

However in the Lesotho Highlands, households' asset bases are very limited and the most valuable asset tends to be the households' land rights for crop production and food security. This is followed by their livestock holdings. These two assets are the primary determinant of vulnerability, i.e. households with insufficient access to land and very little livestock are very vulnerable to shocks and stresses and would therefore be highly dependent on state and community welfare to cope and recover.

Other assets that are important to households' daily well-being and resilience include those which help them to meet their cooking, heating and safety needs, for example:

- Paraffin stoves that can be used for cooking rather than crop residues and cow-dung
- Beds and blankets for warmth in winter
- Radios and televisions for broadcasting important information

The following human capital assets improve the households' capacity to use other existing assets better, and create new assets and opportunities:

- Financial and capital resources
- Marketable skills

***h) Crime and stock theft***

The risk of Livestock theft undermines the investment households make in highly valuable livestock assets, and can have a devastating effect in a household's asset base which it relies on to maintain its resilience to vulnerability. Livestock theft has a potential to cripple a household's livelihood in the following:

- It affects households' opportunities to consume resources such as milk, meat and wool
- it restricts households ability to sell livestock and to earn incomes in order to pay for important events and ceremonies such as weddings and funerals
- It results in a loss of income from sale of livestock by-products and thus limits the use of the proceeds to acquire other food and non-food products they cannot produce themselves

Livestock theft was reported to be common particularly in the cattle post areas.

***i) Health challenges***

The widespread health problems such as the prevalence of HIV/AIDS, Tuberculosis and other lifestyle diseases in the Highlands deplete households' labour base and productivity. Health influences the demand for agricultural outputs, and in agricultural communities in particular, poor health reduces work performance, reducing income and productivity and perpetuating a downward spiral into ill-health (Hawkes and Ruel, 2006). When family members cannot work either because they are sick or they are looking after the frail, the livelihood strategies of that family suffer.

***j) Tenure insecurity***

While households maintain some level of individual control on their fields and housing areas, land for grazing is managed and used as a communal resource. Without rights to ownership of land, particularly grazing land, households have little or no control over management of rangelands are largely unable to influence decisions regarding the utilization (e.g. stocking rates) of rangelands.

The Lesotho Land Act of 1979 states that land which lies fallow for more than two years in succession can revert back to the allocating authority (Drimie, 2002). Although this was meant to encourage and enhance agricultural productivity though ensuring that all land suitable for crop production is used, this poses a risk for vulnerable households, for example, women and child headed households, who can be further marginalized if this practice is implemented. For example, a woman who has lost her husband may not be able to actively farm the land for two or more years due to a lack of resources and labour. Similarly children who have lost their parents and are too young to engage in agricultural activities could lose their family access to land. It is reported that in some cases older male family members are allowed to use land belonging to a woman or children to produce crops that are used to feed and raise the children. However, it is not guaranteed that widowed women or children will be able to re-secure ownership and use of the land in the future.

While protected by the law, in practice local decisions about land rights do not always protect the best interests of women, children or vulnerable households. Both women and children are not always empowered to make their own decisions about their land, or may not have the necessary resources to make decisions to engage in arrangements such as sharecropping or hiring people to work their land when necessary (Drimie, 2002).

Fear of losing the fundamental foundation of the household's food needs and well-being should encourage households to use land to avoid it being taken away from them. However a range of factors (e.g. diseases, age, frailty, lack of resources for inputs) may prevent households from farming their fields. They are then at risk that the fields may be allocated to other households. Once they have lost access to some or all their fields for cropping the household's ability to produce enough food to meet their basic food requirements is further compromised.

Inability to produce food means that households have to buy food or rely on other households for support. Due to the fact that many households are poor and have limited cash incomes, they are not able to buy enough food. Therefore the loss of land due to insecure tenure has trickle down effects on household livelihood strategies and their resilience.

### *k) Shift in institutional powers*

A combination of traditional and democratic institutions at village, community and district level are responsible for land allocation, infrastructure and services, decision making, planning and development and coordination of development activities. Historically, the functions of land allocation and maintaining order and social cohesion among the community resided in the powers of Local Chiefs and village headmen. The Principal Chiefs assumed district wide responsibilities, e.g. land allocation in the cattle posts. The introduction of local government has resulted in the establishment of District and Community Councils, which have taken over some level of power over the function of land allocation, and local economic development, grazing control, HIV/AIDS coordination, services (such as water supply) and natural resource control.

In some Districts and villages, the differences in roles and responsibilities between the traditional and democratic authorities may be clearly defined, however evidence shows that there are gaps and conflicts in between roles and responsibilities of the different institutions (Moran, et al., 2009). For example, there have been reported incidences where councilors have 'replaced' the chiefs and are in charge of community affairs. Local Chiefs want the allocation of land and control of cattle post areas in their area of jurisdiction to be their responsibility instead of local authorities. This will allow them to collect livestock pound fees as they have done before (Shale, 2004), giving them a level of power and authority which in turn is lost by the chief

The shift in institutions responsible for land allocation and managing land resources in the Highlands poses various challenges. Historically, Local Chiefs were responsible for this function. However, it has since been the responsibility of the democratically elected Community Councils. The shifts in institutional are often associated with change in powers, rules, regulations and processes which may impact negatively on people's livelihoods.

Therefore, fragile and unstable institutional arrangements compromise economic and infrastructural development. A shift of land allocation powers from Local Chiefs to Community Councils has led to the formation of bureaucratic administrative units, decentralization which have both resulted in slow land allocation. This affects the capacities of households to meet their pressing livelihood needs.

***l) Access to services***

i. Water and sanitation

There are few piped water systems supplying clean water to households in the Highlands, and the pilot sites in particular. Most households rely on springs, wells and streams to meet their domestic water needs. These water sources are often shared with livestock, as some of them are not protected. For example, some households in Muela and Lejone have access to clean water through communal water stand pipes and some individual household connections, village such as Ha-Koporale, Ha-Ts'iu, Sepinare, Kosetabole and Ha-Poli have to rely on springs, wells and streams. Households relying on unprotected water sources are therefore exposed to greater health risk associated with waterborne diseases.

Reports suggest that about 52% of the population in Lesotho do not have access to adequate sanitation facilities, and the majority of these reside in rural areas (United Nations, 2008). Lack of access to adequate sanitation exposes households to numerous health risks and vulnerabilities, including waterborne diseases and infections. In the pilot sites however, a sanitation programme implemented through the Lesotho Highlands Water Project has resulted in 94% of households having access to ventilated pit latrines sanitation services. However, the trends at project sites are not representative of the Highlands in general.

There are notable disparities in access to adequate water supply and sanitation facilities in the Highlands. Inadequate access to drinking water exposes households to a range risks and vulnerabilities, such as diseases and infections as well as not enough water for domestic use. Likewise, lack of access to safe sanitation facilities the transmission of viruses and diseases. Inadequate sanitations facilities can contaminate water sources critical for domestic use.

ii. Energy sources

Households in the Highlands depend on a number of fuel sources to meet their domestic energy needs. Primary sources of energy for meeting domestic energy needs in the project sites include plant materials for fuel (including wood and shrubs species), paraffin, candles and cow dung. About 51% of the households at the project sites use plant materials as the main energy source for cooking. However due to the scarcity of fuel materials, approximately 23% of the households use cow dung, and 4% rely on crop residues to supplement their domestic energy needs (SMEC, 2010).

The use of cow dung, which is currently the second most utilized source of domestic energy needs in the Highlands, and crop residues is however being discouraged by the

Integrated Catchment Management programme (SMEC, 2010), on the basis that cow dung and crop residues are important for improving soil nutrients. Until alternatives are readily available there is unlikely to be a significant shift in these practices.

The scarcity of domestic energy sources has a range of implications for households' livelihoods and health:

- It limits the number and extent of cooked meals that households can prepare a day.
- It limits the types of foods that households can cook, e.g. foods that require long cooking time may not be feasible.
- A scarcity or shortage of fuel may limit the extent to which families can heat their homes which can result in hardship and health risks in winter and particularly during extremely cold periods.

**Figure 2.3.2:** Villages in the Highlands are characterised by limited infrastructure and services with households largely dependent on direct access to resources to meet domestic water and energy needs as well as building materials

iii. Communication

Communication is vital for networking (e.g. between family members) and broadcasting useful and important information (e.g. weather warnings). The most common forms of communication relied on in the Highlands is radios and cellular phones. However, not all households have access to these mediums of communication. Approximately 68% and 60% of the households at the project sites have access to radios (to regularly listen to news broadcasts) and cellular phones respectively (SMEC, 2010). This limits households' ability to have reliable access to information that is useful for decision making particularly on matters such as livestock management and crop production. Households that do not have access to these useful means of communication and sharing of important information can be exposed to increased levels of risk particularly during extreme events

***m) Weakening social welfare and support networks***

Social and welfare programmes, both State and Traditional, play a crucial role in the well-being and resilience of households. State support includes a number of initiatives and programmes such as:

- Pensions of an amount of M300 are paid by monthly the State to individuals that are 70 years of age or older (Thathane, 2009). This is a critical source of cash income for the whole household.
- Orphaned and Vulnerable Children (OVC) Programme – home based care is provided to the sick and vulnerable particularly orphaned children and child headed households
- Community Health Workers – provide a range of home based health care support

Traditional support systems are important for social cohesion and promoting well-being within villages and communities, and help to bond households within a community (Ubuntu). Households provide support to each other at critical times of need for example to plough, plant and harvest fields to ensure that every family is able to harvest a maize crop each year. Through the collective support of the village, Households that do not have their own means to plough and prepare their fields (e.g. too old, no draught animals, etc.) are still able to plant and harvest their crops to meet household food needs.

Examples of traditional social support systems in the Highlands are:

- *Mafisa* –richer families with large livestock 'loan' their livestock to poorer households who then tend and care for the herds in return for milk and use of by-products such as cow dung, ploughing of fields, etc.
- *Matsema* – households work collectively during labour intensive agricultural periods such as ploughing and harvesting.
- Cultivating and harvesting of Chief's fields to feed the destitute households in the community.
- Burial Societies – used as a savings scheme that many poor households depend for burial needs
- Wool Associations – not only bring livestock owners together but, also provides opportunities for sharing new information.

The practice of traditions such as *lobola* payments and ancestral ceremonies also serve to strengthen social links and bonds within and across households.

A number of Food Aid Programmes distribute food aid to households in the Highlands. It forms an important support system to households during food shortages caused among other factors by crop failures and low crop yields. About 22% of the households have benefitted from food aid at certain times (SMEC, 2010). While food assistance is typically directed at household level, other programmes operate at a primary school level to address starvation and malnutrition among school going children. While food aid is an important supplement to the livelihoods of households in the Highlands, it is not guaranteed and cannot be relied on as the timing and quantity is not assured.

These social and welfare support initiatives play an important role in building and maintaining a strong sense of community, i.e. social capital, as one of the key livelihood assets. However, it has been suggested that it is the village elders who encourage cultures and beliefs, and lead the various rational practices in the villages and that many of the younger generation are not strong practisers of the traditions and are therefore are not as motivated to support practices such as

*Matsema* without the encouragement of the elders. There is therefore a risk of a weakening of these social support networks, and this could contribute to a gradual weakening of the social cohesion in villages and can increase exposure of the most vulnerable households.

## 2.4 Approaches to and outcomes of scenario building

### Introduction to scenario building

The Millennium Ecosystem Assessment's Scenarios Working Group (Millennium Ecosystem Assessment 2005a) considered the possible evolution of ecosystem services during the twenty-first century by developing four global scenarios that explored plausible future changes in drivers, ecosystems, ecosystem services, and human well-being. This scenario building approach was adopted to systematically and creatively think about plausible futures.

Scenario building generates plausible alternative futures (i.e. what might happen under particular assumptions futures) by focusing on key drivers, multifaceted interactions, and complex uncertainties. Mitigation and adaptation strategies can then be assessed within each of these scenarios. These might also include scenarios reflecting no restoration or adaptation.

The scenario building process (as applied in the Millennium Ecosystem Assessment and in this Project) generally involves eight key steps:

1. ***Identify focal issue*** – The focal issue represents the question about the future that the project is confronting, i.e. the key question that will be answered by the scenarios
2. ***Identify driving forces*** – Driving forces represent key variables and their trends in the macro-environment that influence the focal issue (key question). Driving forces may be groups into driving force clusters to make them more workable.
3. ***Rank importance and uncertainty of driving forces*** - Driving forces are ranked in terms of their uncertainty and importance/impact in relation to the focal issue. This step directs the identification of the two most important and uncertain drivers defining the most divergent and relevant future conditions to be included in the scenario logics
4. ***Select scenario logics*** – Logics are defined by exploring the interactions of the most uncertain and important drivers. Two attributes are selected for the driving force selected in Step 3. These attributes represent two polar directions in which the drivers can go in the future. Alternative frames are created for the attributes of the two driving forces, each representing a divergent yet plausible scenario.
5. ***Flesh-out the scenarios*** – Narratives are developed for each scenario by exploring the implications of alternative trajectories on the focal issue under the set parameters defined by the interactions between the key driving forces.
6. ***Select indicators for monitoring*** - A set of indicator are selected to assess the implications of alternative futures (represented by each of the scenarios) on the focal issue.
7. ***Assess impacts for different scenarios*** - Selected indicators are applied to assess how the focal issue is impacted under each scenario.
8. ***Evaluate alternative strategies*** - Once alternative scenarios are described, the efficacy of alternative strategies can be assessed across the suite of scenarios. Note – this step was not

included in the current scenario building process as it will be undertaken once the climate change scenarios are super-imposed onto these scenarios of lively futures in the Lesotho Highlands. This step will then form the approach for identifying appropriate adaptation strategies.

For the purposes of this Project, the scenarios have been used to assess future changes in human well-being and socio-economic systems in the Lesotho Highlands over the next 50 years and beyond[2], and to highlight the consequences of these changes to ecosystems and resulting ecosystem services. Adopting the long time horizon accommodates the consideration of many salient but slow trends in human population development and ecosystems, which only become visible over this long time period, but for which decisions influencing these trends will be taken in the immediate future. It also allows for the identification of robust adaptation strategies that will be relevant and applicable well into the future.

Land use expansion and changes in the Lesotho Highlands are some of the most critical aspects of anthropogenic change that influence the future of ecosystems and their services. Land use changes will directly determine many of the provisioning and regulating functions of ecosystems, by causing for example changes in biodiversity and/ or wetlands. Land use patterns in turn are driven by factors such as demographic, economic, and technological changes. There are however also indirect effects on human behaviour and future ecosystem services, such as those that can result from other global changes (e.g. climate change). These will also be superimposed on the future scenarios developed and in this way used to identify adaptations strategies for the resilience of livelihoods and ecosystem functioning in the Highlands.

## Scenario building process applied in the Project

The scenario building steps (as outlined in section 2.4.1 above) were followed during a three phase process to build scenarios for the Project:

a) ***A specialist scenario building workshop***

This workshop was held with a number of rangeland management, environmental, hydrological, agricultural, climate change and livelihoods specialists. The outcomes of the agricultural, environmental and livelihoods status quo assessments undertaken earlier in the project were used as baseline information to inform the scenario building process.

b) ***A national stakeholder workshop***

The scenario building process was repeated with national stakeholders in Lesotho, with the draft scenarios developed at the specialist workshop used as baseline information. Representatives from project partner Ministries, Departments and Projects in Lesotho engaged in this process to fine tune and corroborate the scenarios as reflective of plausible futures in the Lesotho Highlands.

[2] These timeframe align with the climate change scenarios i.e. the intermediate future (2046 – 2085) and the more distant future (i.e. 2086 – 2100).

***c) Village level workshops***

Eight scenario building workshops (split over two events at each site) were held at the Project pilot site communities in the Highlands. The four scenarios developed together with the national stakeholders were used as the baseline information for the village level scenario building process. Again this process was used to corroborate the key aspects of the scenarios to ensure they had local level support as being reflective of plausible futures in the Highlands.

The scenarios were refined and some of the details expanded during each of the phases, and no conflicts or contradictions were recorded across the events.

## Summary of outcomes of the scenario building process

The section below summarises the outcomes of the seven steps in the scenario building process that were followed in this project. The eighth step (evaluate alternative strategies) was not included in the scenario building process, as it will be addressed as part of the process to identify and select adaptation strategies once the scenarios have been superimposed with the climate change parameters.

***a) Focal Issue / Key Question***

Question about the future that the project is attempting to address is:

> *What are the implications of land use and management approaches for resilience of livelihoods and ecosystem functioning of the Lesotho Highlands environment in face of climate change?*

***b) Driving Force Clusters***

Driving forces are defined as the Key variables and their trends in the macro-environment that influence the focal issue. Driving forces were first identified within each of the Project's three focus areas:

- Ecosystem context
    - Rangeland management practices
    - Natural resources governance
    - Biodiversity loss
    - Socio-economics
    - Natural events / forces
- Agriculture context
    - Policy environment / government
    - Socio-political dynamics
    - Governance systems
    - Land use management
    - Environmental characteristics
    - Population dynamics
- Livelihoods context
    - Population dynamics
    - Socio-political forces
    - Economic dynamics
    - Skills and technology levels

Driving forces can then be clustered into Driver clusters. Clustering process is important in making a large set of drivers more manageable from an analysis perspective. The three sets of driving forces were therefor clustered into seven driving force clusters:

- Human population dynamics
- Economic dynamics
- Socio-political dynamics
- Policy environment
- Governance dynamics (district and national as well as traditional)
- Land use management dynamics
- Biophysical dynamics (Natural forces and environmental characteristics)

***c) Predictability Matrix***

The predictability matrix is used to identify the two driving forces that are likely to have the greatest impact / importance in shaping the future but are the least predictable or have the most uncertainty. The graph below illustrates the outcome of plotting the seven driving force clusters on the matrix and the conclusion that (a) socio-political dynamics and (b) economic dynamics are the two clusters that will have the greatest impact in shaping the futures in the Lesotho Highlands, yet at the same time are the least predictable in terms of what that impact will be.

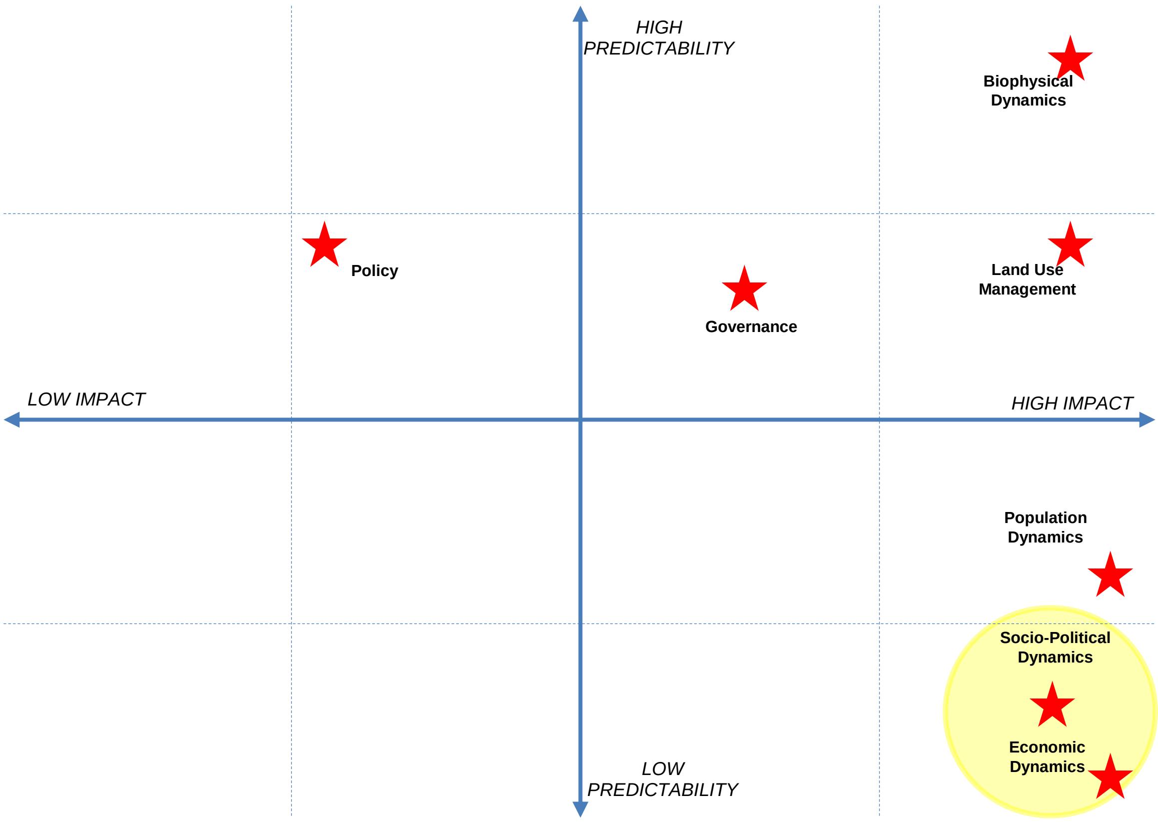



**Figure 2.4.1:** Predictability matrix highlighting most uncertain drivers with highest impact

While there was a level of disparity in the location of the driving forces on the predictability matrix across the various scenario building workshops (specialist, national and village level), the selection of socio-political dynamics and economic dynamics as the two most unpredictable and important was consistent.

***d) Scenario Logics and Driving Force Attributes***

Attributes for two polar directions for each of the target driving force clusters identified in Step 3 (above) were selected as follows:

a) Economic dynamics
   - Commercial multi-sector economy[3] with capital investment
   - Non-commercial single sector economy (agriculture) with no to no capital investment

b) Socio-political dynamics
   - Stable structured society
   - Unstable unstructured society

The four resulting scenario logics are outlined in the figure below. The narratives for these scenario logics are described in Step 5.

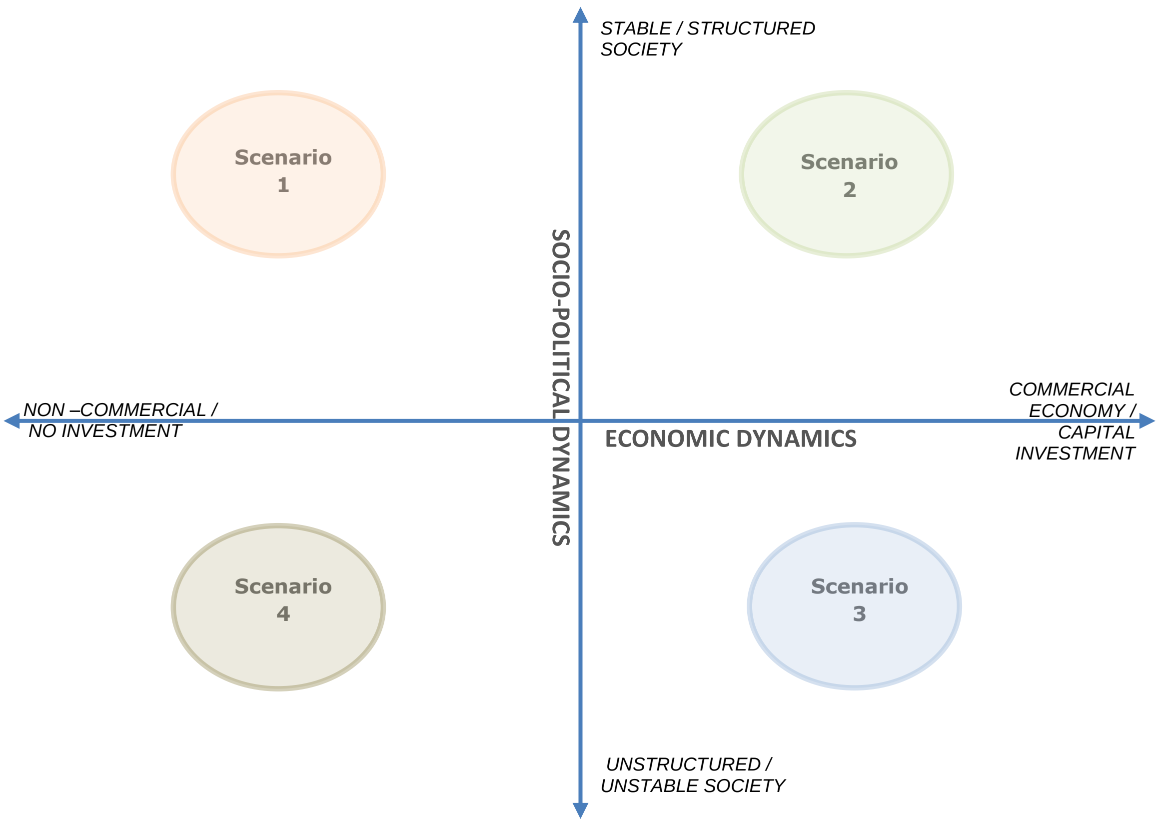



**Figure 2.4.2:** Matrix illustrating four scenario logics

[3] The definition of commercial in this case is defined relative to the context of the Lesotho Highlands rather than a capital intensive urban economy.

The scenarios were then 'named' as follows:

- Scenario 1 - Tortoise and translated as *Khotso* (peace) in Sesotho
- Scenario 2 - Rabbit and translated as *Khora* or *Nala* (prosperity) in Sesotho
- Scenario 3 - Vulture and translated as *Lekanyane Hophela Leliretse* (survival of the fittest) in Sesotho
- Scenario 4 - Jackal and translated as *Tlala* or *Bofuma* (poverty/deprivation) in Sesotho

### *e) Scenario storylines*

The story lines are aimed at exploring the implications of the trajectories on the focal issue (key question) under set of parameters defined by intersection of driving forces (and attributes). The figure below (Figure 2.4.3) summarises the key parameters of each scenarios. These are translated into full narratives in Section 2.4.4.

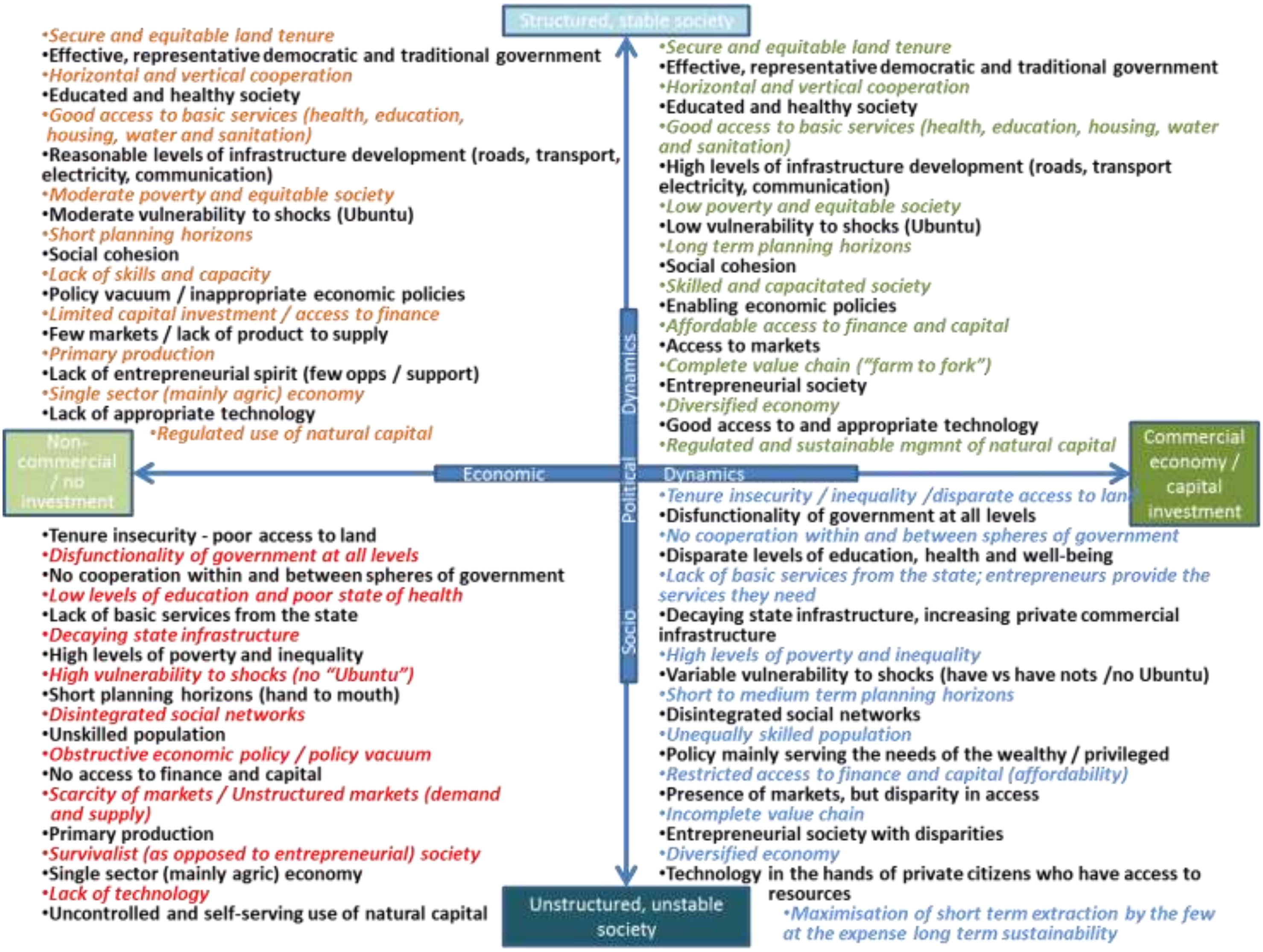



**Figure 2.4.3:** Summary of scenario storyline key parameters

***f) Selecting Indicators***

Indicators for assessing implications of scenarios on resilience of livelihoods and ecosystem functioning were clustered into three criteria:

1) Impacts to ecosystem assets and services
2) Impacts to biodiversity
3) Impacts to livelihoods and human well-being

The indicators for each criterion are listed below:

1) Ecosystem assets /services
    - Water supply into the LHWP System
        - Flow amount
        - Quality
        - Variability (intra-and inter seasonality)
        - Timing of flow
            - base flow
            - storm flow
            - seasonality
    - Forage supply (grazing)
        - Rangeland composition (condition)
        - Rangeland production
            - Alpine grassland integrity
    - Livestock production (amount and offtake)
        - Goats and Sheep (Mohair and wool production and meat, milk?)
        - Cattle (Meat, milk and culture, and draught)
        - Donkeys and horses (Draught power and transport)
    - Crop production
        - Grains (Distribution [where grown] and yields)
            - Maize
            - Wheat
            - Sorghum
        - Vegetables and fruit
            - Cabbage
            - Peas
            - Potato
            - Peaches
        - Woodlots
        - *Cannabis*
    - Harvestable natural resources (indigenous)
        - Medicinal plants
        - Foods
        - Fuels and energy
        - Building materials (thatch and wood)
        - Fibre
    - Soil
        - Suitability (depth, moisture retention, drainage Quality / fertility)
        - Erosion rates
        - Erosion control
            - Sediment retention
        - Nutrient loading (cycling)
            - Quality / fertility

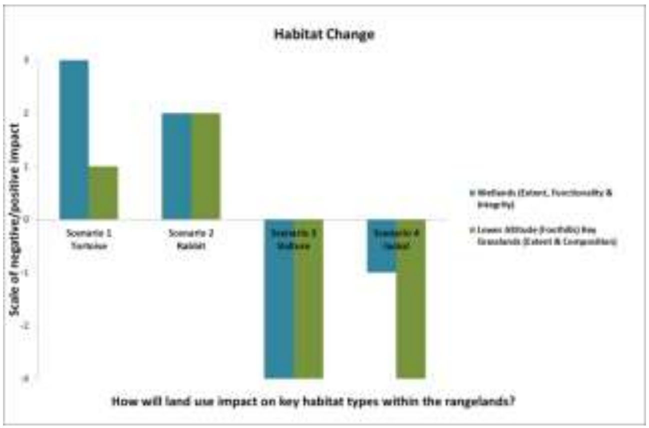
2) <u>Biodiversity</u>
- Habitat change
    - Alpine grasslands
        - Extent
        - Composition
    - Wetlands
        - Extent
        - Functioning and integrity
    - Lower altitude (foothills) key grassland types and species *(eg Themeda, Hyparrhenia)*
        - *Extent*
    - Shrublands *(Leucosidea and Chrysocoma)*
        - Extent
    - Riparian vegetation
        - Woody composition
- Fire patterns
    - Intensity
    - Seasonality
    - Return period
- Invasive species
    - Abundance / density
    - Distribution

3) <u>Human well-being</u>
- Livelihood needs and strategies
    - Material wealth
    - Diversification
    - Resource based
    - Non-resource based (value adding/beneficiation/value chain)
- Land/tenure security
    - Population growth/densities
    - Access
    - Land suitability
- Health and nutrition
    - Food security
    - Water quality and quantity
    - Prevalence of lifestyle and pathogenic diseases
    - Welfare and Aid support
    - Service delivery
        - Access
        - Quality
        - infrastructure
- Social cohesion /relations and security
    - Migration
    - Governance systems (traditional and district)
    - Social networks

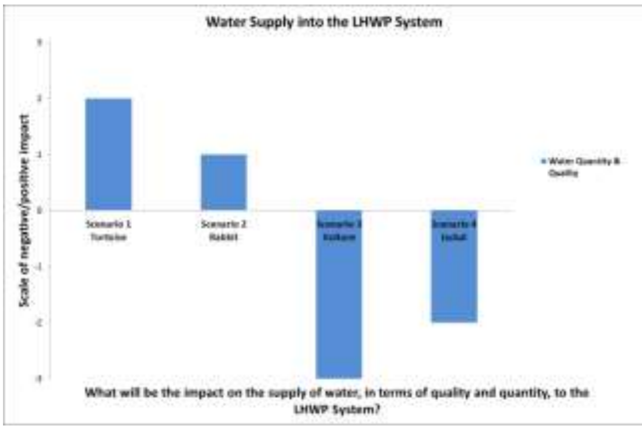
***g) Assess impacts of each scenario***

Indicators listed above were then applied to assess the impact to the focal issue under each scenario. This was expressed in a graph form, examples of which are listed below:

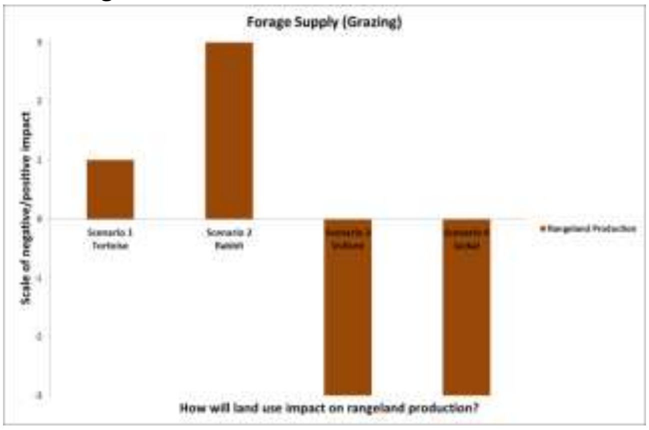
Example 1: Likely changes in natural habitat in Highlands Catchments



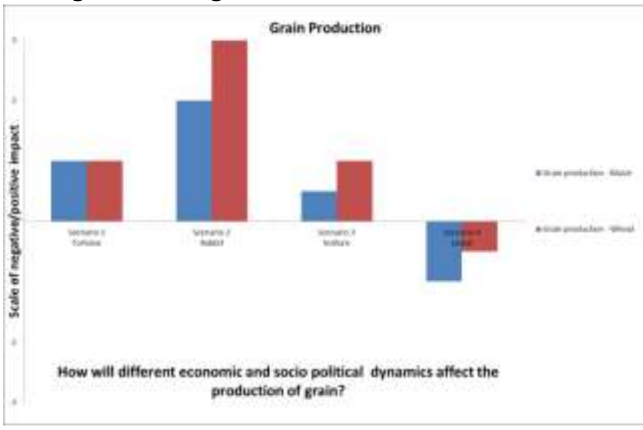

Example 2: Indicator of water yield from the Highlands Catchments



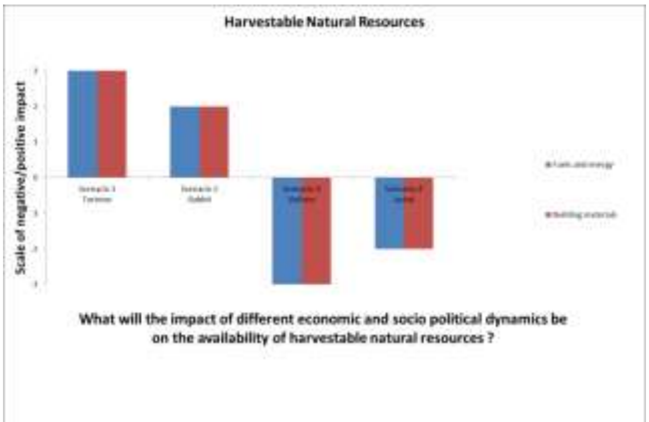

Example 3: Implications for forage supply in in the Highlands



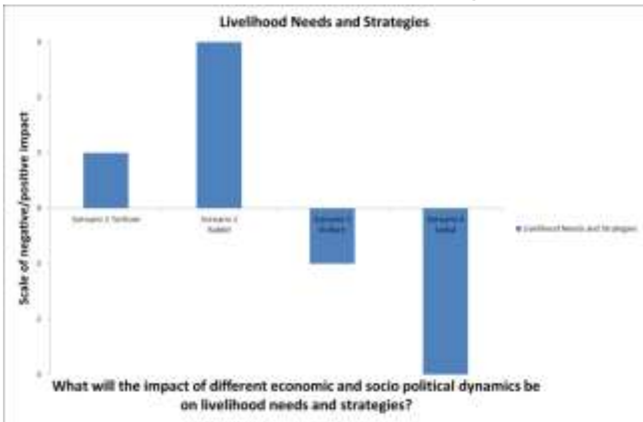

Example 4: Implications for grain production the Highlands rangelands



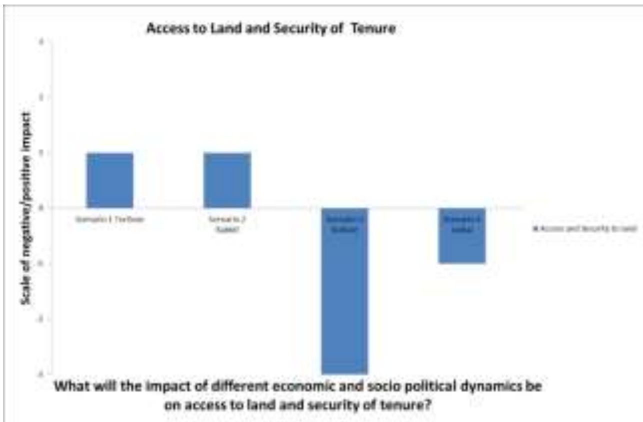

Example 5: Implications for availability of harvestable natural resources



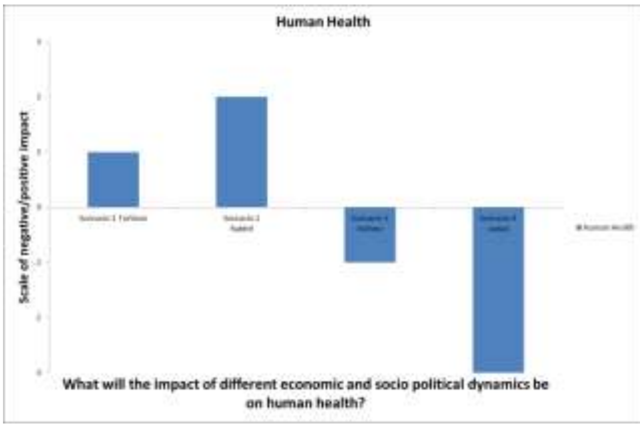

Example 6: Implications for meeting livelihoods needs and livelihoods strategies



Example 7: Implications for access to land and tenure security




Example 8: Implications for human health




## Scenario narratives

### *2.4.1.1 Tortoise (Khotso) Scenario*

Given current population growth trajectories in Lesotho (i.e. nearing zero) the environmental pressures associated with population growth will increasingly become a non-factor, i.e. resource use will not increase as a direct result of increasing needs of a growing population in the Highlands. However, largely unabated poverty levels will continue to drive resource use by households and overall pressures on the environment are likely to continue growing, driven by the need to meet the survival requirements of poor rural households.

Strong and fair governance systems and social cohesion linked to the stable and structured society translates into good governance in democratic and traditional leadership systems, sound planning systems and an equitable and fair society. This contributes to secure tenure and property rights as well as reasonable levels of infrastructure development and service delivery (e.g. health care, education etc.). Despite the strong governance systems, the lack of skills and capacity results in a policy vacuum and existing policy that is largely inappropriate to address the real developmental and environmental challenges in the Highlands. This together with a shortage of appropriate technology and access to finance inhibits the diversification of the local economy, which remains largely a single sector economy based on agricultural production.

The good levels of social cohesion and the equitable society contributes to commitment to the regulated use of natural resources in the Highlands and particularly improved management of the commons and open access resources. Improved natural resource governance and social cohesion also encourages collective responsibility and actions to overcome environmental degradation, such as soil erosion and fire management. However the effectiveness of these efforts will be limited due to poverty and lack of skills and resources.

Lack of economic development opportunities results in communities that are still characterised by widespread and relatively high levels of poverty. A shortage of skills restricts households' ability to move beyond primary agriculture.

Livestock production remains a key livelihood strategy for Highlands' households. A lack of skills and appropriate technologies results in little or no livestock improvement, with households still largely driven to maximise the quantity rather than quality of their herds. While social cohesion contributes to some regulation and management of herd sizes (regulated through permit systems) and therefore the control of the total number of livestock grazing in the rangelands, the lack of locally effective policy and capacity limits effectiveness of grazing management plans. There is therefore some improvement in rangeland condition associated with the restriction of livestock numbers, but this is not optimised for animal production or biodiversity.

Households are still primarily dependent on cropping to meet household food security needs. Again, the lack of skills, capacity, and access to finance to invest in improved farming systems limits households' ability to diversify crop production or to increase yield from existing fields. Therefore land use pressure for expanding fields continues to increase as households try to increase their production levels.

Population growth in the short term still results in a level of settlement expansion, but the strong social cohesion results in expansion of existing settlements rather than the establishment of satellite village settlements. The expansion of settlements that are moderately to poorly serviced results in increased environmental pressures and negative impacts such as pollution. Limited infrastructure e.g. no energy supplies will still place high pressure on natural fuel resources.

Increased anthropogenic pressures on the environment will result in biodiversity loss and environmental degradation, which may struggle to recover even though population growth will stabilise in long term.

#### *2.4.1.2 __Rabbit (Khora / Nala) Scenario__*

Key attributes of this scenario are a structured stable society and a diversified economy with access to finance and capital for investment. This contributes to local economic growth and enterprise development in the Highlands, which positively impacts on unemployment and poverty.

Strong and fair governance systems (both democratic and traditional) together with economic growth result in an enabling policy environment and long term planning horizons. This allows for investment in infrastructure and services such as health care and education, which in turn results in improved skills levels and capacity in the Highlands' communities. Positive economic trends, social stability and improvements in health care, in particular, translate into positive population growth rates in the longer term. However population growth is still relatively low.

Access to land is fair and equitable and there is security of tenure for land held by households. Poor households' access to land is also protected through this secure tenure and social cohesion.

Improved skills, access to technology and financing results in an improvement in the quality and productivity of farming systems.

Livestock improvement increases returns from herds and reduces the dependence by households on large herds of livestock to provide livelihood security. While poverty levels are relatively low, the poorest households are still motivated to maximise herd sizes as a livelihoods resilience strategy. Social stability and effective governance systems do however contribute to strict control of livestock numbers and grazing plans, which contributes to overall improvement in rangeland condition.

Investment in agricultural skills, the promotion of appropriate technologies and access to finance enables households to diversify crop production and to increase yields. Every household has access to sufficient land to meet their food requirements. This means that food security is enhanced and households are less vulnerable to shocks and extreme events. Farmers who have access to larger croplands are producing surplus which they are selling for profit. Meeting the food needs of a growing population in combination with farmers seeking to increase yields and profits from their crop production means that pressure to cultivate new lands remains high. Expansion is, however, controlled and restricted to suitable cropping areas through good governance and effective policy and enforcement (e.g. land capability classes 5, 6, 7 and 8 are protected and land use in these areas is regulated).

Diversification in the local economy facilitates opportunities for local value adding and beneficiation within the Highlands. This creates opportunities for improved economic returns from livestock and crop production activities.

Poverty reduction and economic upliftment of communities results in the expansion of settlements but improved policy and planning results in parallel improvements to infrastructure and services, which limits negative impact to environment. Improved access to appropriate technology also encourages the implementation and uptake of environmentally friendly and clean services such as solar energy and rainwater harvesting. This reduced anthropogenic pressures on the environment particularly in the immediate vicinity of the settlements.

Effective governance will result in controlled use of communal resources and reduced poverty levels will reduce demand for and pressure on natural resources such as fuel materials (e.g. *Leucosidea* and *Artemisia* sp) fibres and indigenous fruits, foods and medicinal plants. This could have a positive impact on biodiversity.

Social cohesion, governance and planning will encourage community efforts to overcome environmental degradation, and the positive impacts of these rehabilitation efforts will be enhanced due to availability of skills and access to technical and financial resources to invest in actions. Government interventions will be maximised due to good policy and access to finance. However if resource use is not responsibly managed, the risk remains that increased and irresponsible resource use and environmental degradation may occur to fuel the economic growth.

#### ***2.4.1.3 Vulture (Lekanyane Hophela Leliretse) Scenario***

Defining attributes in this scenario are a diversified economy with disparities in access to finance resulting in some economic development and diversification in the economy on the Highlands. However unstructured and unstable social environment results in disparate distribution of these benefits with an increasing gap developing between an opportunistic and entrepreneurial minority (the 'haves') and a disadvantaged and un-capacitated majority (the 'have-nots'). This disparity further drives the breakdown in social cohesion and a sense of each household looking only after its own interests.

A lack of economic opportunities among the disadvantaged majority results in on-going unemployment and poverty, and a largely subsistence agriculture economy in the Highlands. Population growth trajectories are near zero, and environmental pressures associated with population growth increasingly become a non-factor (i.e. resource use does not increase as a direct result of increasing needs of a growing population). However, the largely unabated poverty levels continue to drive resource use by a large percentage of the households, and therefore overall pressures on the environment continues to grow, driven by the need to meet survival needs of poor rural households.

Livestock operations are mixed with a few large, well maintained, commercially oriented, herds owned by '*haves'* who have access to financial resources and skills to advance livestock improvement. However there are also a large number of small subsistence herds owned by *'have-nots'* who have limited skills and resources to invest in livestock improvement. These households are therefore still motivated to maximise herd sizes as a strategy to reduce their livelihood vulnerability. There is very little control of livestock grazing and numbers as the 'haves' use their influence to manipulate grazing management plans in their favour at the expense of the subsistence livestock owners and the long term sustainability of the rangelands.

Skills and access to finance provide opportunities for the advantaged 'haves' households to diversify their livelihood strategies with a level of local value adding and beneficiation resulting in diversification of the local economy. This further increases the relative wealth of the '*haves'*. Lack of capacity and capital locks the '*have-nots*' in primary and subsistence level crop production as the primary livelihood strategy, exacerbating the disparities in wealth and well-being within communities. In some cases, '*have-nots'* cannot afford to cultivate land and are, after two years of non-cultivation it is forfeited. The more advantaged 'haves' use their influence to secure the reallocated land thereby further improving their position and well-being but at the expense of the poor 'have-not' households whose resilience is further weakened.

The increased income opportunities associated with value adding activities, coupled with the lack of effective governance and planning, result in unscrupulous and irresponsible expansion of cultivation, into productive, but and environmentally sensitive areas. This contributes to environmental degradation, particularly of sensitive areas such as wetlands, and biodiversity loss.

Tenure insecurity and disparate access to land results (attributed to weak social structures and a lack of social cohesion) result in increased risk of the '*have-not'* households losing land to the more advantaged and locally influential households. The '*have-not'* households are therefore forced to expand their cropping activities into marginal areas which have very low yields resulting in increased vulnerability of these households despite the efforts they put into food production. The increasing land use pressure on marginal areas again exacerbates environmental degradation.

High levels of poverty among a portion of the population coupled with the lack of governance and social cohesion also escalates unsustainable harvesting pressures on natural resources used to supplement poor households' livelihoods. This includes fuel materials and indigenous fruits and foods in particular.

Settlements tend to expand and sprawl across the landscape because of lack of planning, governance and social cohesion. Economic disparities result in variation in levels of access to infrastructure and services, with the advantaged households in a position to invest in infrastructure and services to meet their own private needs, without investment in communal resources. However, the fact that the advantaged households make up only a minority of the community means that the expanding settlements and the relative increase in poorly serviced households escalates environmental and pollution pressures associated with residential areas.

Despite widespread environmental degradation, the lack of social cohesion and effective governance means that there are no rehabilitation or conservation initiatives at all. Maximisation of short term resource use by all households to meet their own self-interests takes place the expense of long-term sustainability.

#### *2.4.1.4 Jackal (Tlala or Bofuma) Scenario*

This scenario's defining attributes are an unstable and unstructured society with no social cohesion or governance. This is in conjunction with a single sector undiversified local economy founded largely on subsistence level agricultural systems as a result of lack of access to any capital for investment in economic development. Lack of economic growth results in on-going unemployment and poverty, and the absence of effective governance and inappropriate policy all result in no planning or investment in critical infrastructure and services such as health care and education. Population growth rate very quickly becomes negative because of increasing poverty and lack of health care. This results in skewed age distribution in the population with land and resources primarily in the hands of the elderly who are unable to utilise and work the land to its full capacity. Declining health care and welfare support results in increasing incidence of child headed households, and very high vulnerability and dependency levels in the Highlands.

The lack of economic opportunities, social cohesion and governance means that each household is heavily reliant on their own ability to meet their livelihood and food security needs.

The absence of effective governance systems, including management of resource use, results in a classical 'tragedy of the commons' scenario, and is reflected in declining production in all agricultural systems. Large livestock herds in very poor condition, vulnerable to disease and high mortality rates are the norm. Uncontrolled grazing patterns, with indiscriminate grazing of summer cattle posts and lower altitude winter rangelands exacerbate rangeland degradation, and loss of important habitats such as wetlands.

Crop production is typically focused on a single staple crop, i.e. maize, but a lack of technology, skills or resources to invest in inputs results in declining crop yields and increasing vulnerability of households' food security. This pressures households to expand their field sizes in an effort to maintain overall harvest levels. Uncontrolled expansion of cropping areas, even into marginal and fragile zones, also contributes escalating degradation of the natural environment. Widespread problems such as erosion and alien plant invasion are left unaddressed with no efforts or resources allocated to rehabilitation.

The absence of capital investment, technology and skills means that there is no local value adding and households typically consume whatever they are able to produce. There is therefore no local market or trade. Households need to be self-sufficient in terms of meeting their own food security needs. Lack of effective governance (democratic or traditional) means that there are no social welfare support systems, no investment in local infrastructure or services. Health levels are low and population growth rates quickly become negative resulting in a shrinking population in the Highlands. Settlement sizes are static with a lack, or declining levels, of services. This results in intensifying environmental degradation and pollution around settlements, characterised by high levels of poverty.

There is unscrupulous use of natural resources by households trying to survive, with everyone only concerned by meeting their own needs and maximising whatever benefits they are able to for themselves. There are no resource conservation initiatives, no rehabilitation of environmental degradation, and uncontrolled self-serving use of natural capital to meet short term needs.

#### *2.4.1.5 Conclusions*

Basic human conditions generally decline for most households across three scenarios, and improve for most households in only one scenario (Scenario 2 - Rabbit). All the scenarios, to a varying extent, depict hazardous and deteriorating paths of ecosystems change, with the Vulture (scenario 3) and the Jackal (scenario 4) illustrating escalating degradation of functioning and loss of associated ecosystems, even in the relatively near future. This reflects the complex linkages and consequential relationships between ecosystem service changes on human well-being. Environmental degradation and loss of ecosystem services leads to degradation of livelihoods and higher inequalities within communities and even loss of social cohesion and traditional support systems that have always provided a level of resilience for rural households in the Highlands. Some of the scenarios include irreversibilities (i.e. degradation that cannot be reversed through rehabilitation) that are the results of cumulative nature of many changes that affect ecosystem services and human well-being.

A common development pattern characterising all four scenarios is the trade-offs made between provisioning and regulating functions of ecosystems that are made as a result of the degradation and loss of some ecosystem services. The drive to alleviate poverty and meet short term basic survival needs (food, fuels, shelter) increases demand for the provisioning services (e.g. harvestable natural resources, fields for cropping, and grazing or livestock). However meeting high levels of demand for provisioning services occurs at the expense of the sustainability of regulating and supporting services. For example cropping of sensitive habitants, overstocking, over harvesting results in environmental degradation and biodiversity loss which undermines ecosystem functioning and the generation of regulating and supporting services. Because of the clear association between crop and livestock production and livelihood security, agriculture is perceived to be the most important provisioning service for addressing poverty alleviation. The importance of regulating and supporting services for livelihood and environmental sustainability is less widely recognized. The loss of regulating and supporting services in exchange for maximizing benefits from provisioning services is therefore considered a reasonable trade off under these circumstances, however with an understanding of the consequences of the loss of supporting and regulating services these trade-offs may be viewed differently.

# 3 DESCRIPTION OF CLIMATE CHANGE IMPACT STUDIES

## 3.1 Background to climate change scenarios

The Bioresources Engineering and Environmental Hydrology Department at the University of KwaZulu-Natal has recently undertaken detailed climate change modelling for South Africa, Swaziland and Lesotho (Schulze, 2010). These analyses were undertaken using the *ACRU* hydrological model (Schulze, 1995 and updates). The traditional 481 quaternary catchments (4$^{th}$ level sub-basins) making up South Africa, Lesotho and Swaziland were sub-divided into 1443 hydrologically homogenous and hydrologically linked quinary catchments (5$^{th}$ level sub-basin). The *ACRU* model is set up for each sub-basin using a range of input data including daily rainfall and temperature as well as information on soils and landcover for each of the quinary catchments. Key input variables such as rainfall amount and distribution, and evaporation are then altered, to model the impact of future climate scenarios on the hydrology and water resources in the quinary catchments.

The future scenarios rely on information from Global Circulation Models (GCMs). In the Schulze (2010) study, future scenarios for the region were determined using information from five GCMs. The GCMs used in the study are detailed in Table 3.1.1 below.

**Table 3.1.1**: Information on GCMs applied in the Schulze (2010) climate change study

| Institute | GCM |
|---|---|
| Canadian Center for Climate Modelling and Analysis (CCCma), Canada | Name: CGCM3.1(T47)<br>First published: 2005<br>Website:<br>http://www.cccma.bc.ec.gc.ca/models/cgcm3.shtml |
| Meteo-France / Centre National de Recherches Meteorologiques (CNRM), France | Name: CNRM-CM3<br>First published: 2004<br>Website:<br>http://www.cnrm.meteo.fr/scenario2004/indexenglish.html |
| Max Planck Institute for Meteorology (MPI-M), Germany | Name: ECHAM5/MPI-OM<br>First published: 2005<br>Website:<br>http://www.mpimet.mpg.de/en/wissenschaft/modelle.html |
| NASA / Goddard Institute for Space Studies (GISS), USA | Name: GISS-ER<br>First published: 2004<br>Website:<br>http://www.giss.nasa.gov/tools/modelE |
| Institut Pierre Simon Laplace (IPSL), France | Name: IPSL-CM4<br>First published: 2005<br>Website:<br>http://mc2.ipsl.jussieu.fr/simules.html |

The GCMs provide a high level view of climate change and consequently their results need to be downscaled to a regional or local level. In the Schulze (2010) study point scale climate change scenarios were generated by empirically downscaling the GCM simulation outputs (Schulze *et al*, 2010). The points at which the scenarios were produced were the locations of climate stations used in the downscaling process. This is particularly important in the context of Lesotho, as only one climate station was available for use in the downscaling process. This reflects the reality of the relatively sparse observation networks of high quality, long duration and readily available data in Lesotho (Lumsden *et al*., 2010). All of the future global climate scenarios that were downscaled were based on the A2 emissions scenario which assumes that greenhouse gas emissions continue relatively unabated to the year 2010.

Regional climate change scenarios were developed for “present”, “intermediate future” and “more distant future” climates represented by the following time periods:

- present climate: 1971 - 1990 (from a possible 1961 - 2000),
- intermediate future climate: 2046 - 2065, and
- distant future climate: 2081 - 2100.

The results of the scenarios are generally expressed as a ratio of values expected in the intermediate or more distant future climates with those currently experienced. Any potential impacts of climate change could then be assessed in relative terms by evaluating whether the ratio of future to present was > 1 or < 1 (Schulze *et al*., 2010).

## 3.2 Results for selected climate variables

Schulze’s study provides results for a wide array of climate variables. It is not possible to present all of these results and thus only selected variables which are likely to have a profound effect on ecosystems, agriculture and livelihoods have been detailed. It is important to note that the information provided by Schulze is intended to show trends across Lesotho, South Africa and Swaziland and provide indications of projected slight, moderate or significant changes. However, for the purposes of this study, this information was extracted at a site level. Given the limitations of the downscaling process, and the significantly reduced accuracy of results at a fine scale, the confidence in this data at a site level is low. ***It is therefore recommended that the results presented here are used as an indication of possible changes rather than as absolute values.*** More detailed analyses at a quinary level are currently being undertaken by the Bioresources Engineering and Environmental Hydrology Department at the University of KwaZulu-Natal and will be used to refine the results in future phases of the project.

### Temperature

Increasing temperatures will not only have a direct bearing on the types of plants and animals that occur in the region and the type of crops that can be grown, but will also affect evaporation and water storage in the earth’s atmosphere. This in turn, will affect the frequency and intensity of rainfall events, the seasonal and geographic distribution and its variability from year to year (Knoesen *et al*., 2009). Rising temperatures will also affect soil moisture, heat wave episodes and meteorological and hydrological droughts.

Historic information indicates that mean annual temperatures are in the order of 10 to 12 ºC for all PCAs except Muela which is slightly warmer (Table 3.2.1). These temperatures are projected to increase in the intermediate future by 2.0 to 2.5 ºC at Muela and Sepinare and by 2.5 to 3.0 ºC at Setibi and Koporale. In the more distant future mean annual temperatures are likely to increase by 5.0 to 6.0 ºC across all PCAs (Figure 3.2.1).

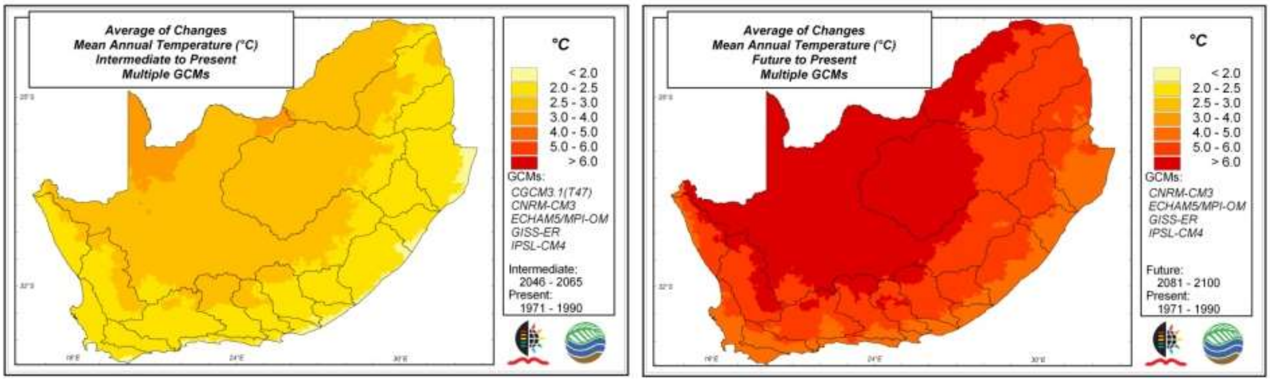



**Figure 3.2.1:** Differences in mean annual temperatures between the intermediate future and present (left), and the more distant future and present climate scenarios (right) for multiple GCMs (extracted from Schulze and Kunz, 2010).

Baseline January temperatures range between 20 and 24 ºC at Sepinare, Setibi and Koporale. At Muela, baseline temperatures are in the order of 24 to 26 ºC. Similarly, July minimum temperatures are less than -2 ºC at all sites except Muela where these range between -2 and 0 ºC (Table 3.2.2). Projections are that both January maximum temperatures and July minimum temperatures will increase by 2 to 2.5 ºC in the intermediate future across all PCAs. However, in the more distant future January maximum temperatures may rise by 4.0 to 5.0 ºC while July minimum temperatures are projected to increase in excess of 6 ºC at some of the PCAs (Figures 3.2.2 and 3.2.3).

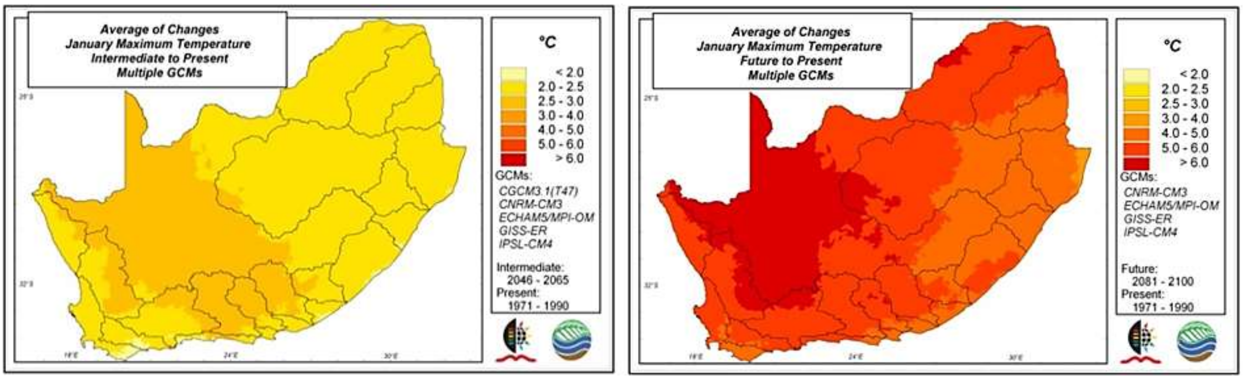



**Figure 3.2.2:** Average of changes in January maximum temperatures between the intermediate future and present (left), and the more distant future and present climate scenarios (right) for multiple GCMs (extracted from Schulze and Kunz, 2010a)

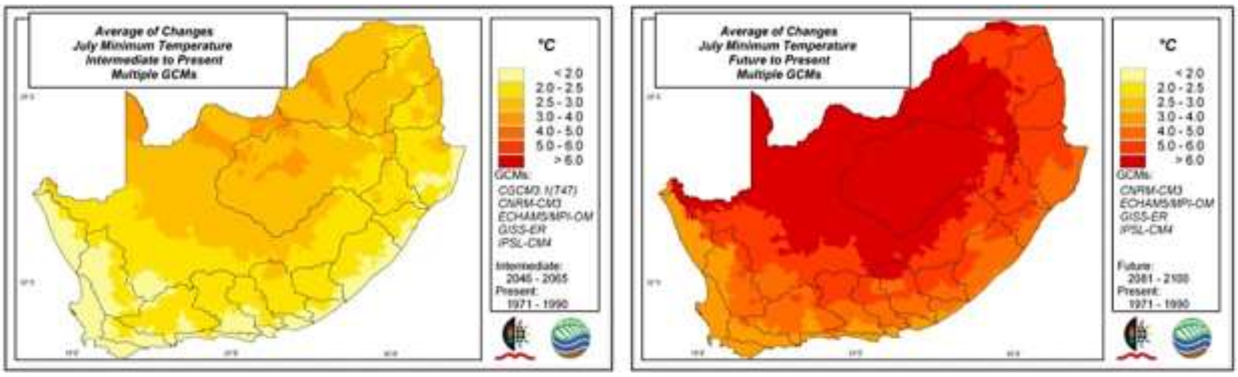



**Figure 3.2.3:** Average of changes in July minimum temperatures between the intermediate future and present (left), and the more distant future and present climate scenarios (right) for multiple GCMs (extracted from Schulze and Kunz, 2010a)

**Table 3.2.1:** Summary of temperature variables for baseline (historical; 1950 - 1999) climatic conditions for each of the PCAs

| Scenario | Site | Mean Annual Temperature (ºC) | January Maximum (ºC) | July Minimum (ºC) |
|---|---|---|---|---|
| Baseline (1950 - 1999) | Muela | 12 - 14 | 24 - 26 | -2 - 0 |
| | Sepinare | 10 - 12 | 22 - 24 | < -2 |
| | Setibi | 10 - 12 | 20 - 22 | < -2 |
| | Koporale | 10 - 12 | 22 - 24 | < -2 |

**Table 3.2.2:** Summary of projected changes in temperature for the intermediate and more distant futures at each of the PCAs

| Scenario | Site | Projected change in Mean Annual Temperature (ºC) | Projected change in January Maximum (ºC) | Projected change in July Minimum (ºC) |
|---|---|---|---|---|
| Intermediate future | Muela | 2.0 – 2.5 | 2.0 – 2.5 | 2.0 – 2.5 |
| | Sepinare | 2.0 – 2.5 | 2.0 – 2.5 | 2.0 – 2.5 |
| | Setibi | 2.5 – 3.0 | 2.0 – 2.5 | 2.0 – 2.5 |
| | Koporale | 2.5 – 3.0 | 2.0 – 2.5 | 2.0 – 2.5 |
| More distant future | Muela | 5.0 – 6.0 | 4.0 – 5.0 | 5.0 – 6.0 |
| | Sepinare | 5.0 – 6.0 | 4.0 – 5.0 | 5.0 – 6.0 |
| | Setibi | 5.0 – 6.0 | 4.0 – 5.0 | > 6.0 |
| | Koporale | 5.0 – 6.0 | 4.0 – 5.0 | > 6.0 |

## Heat waves and cold spells

Extended periods of excessively hot weather on consecutive days on which temperatures are well above normal are referred to as heat waves. Schulze and Kunz (2010b) further defines two categories namely heat waves on which temperatures are above 30 ºC for three or more consecutive days, and extreme heat waves on which temperatures are above (or equal to) 35 ºC for three or more consecutive days. Baseline climatic conditions indicate that there are less than two occurrences of heat waves and extreme heat waves at all PCAs (Table 3.2.3). These occurrences are unlikely to change in the intermediate and more distant futures (Table 3.2.4).

Schulze and Kunz (2010c) also define cold spells as extended periods of cold weather (below 2.5 ºC) on three or more consecutive days, and severe cold spells as three or more consecutive days with minima below freezing point, i.e. 0 °C. Baseline conditions indicate that the number of occurrences of cold spells and extreme cold spells is in the order of 8 to 10 across all the PCAs (with the exception of Muela) (Table 3.2.3). Theses occurrences are projected to decrease by more than 30% in both the intermediate and more distant futures (Table 3.2.4).

**Table 3.2.3:** Summary of heat waves and cold spells for baseline climatic conditions at each of the PCAs

| Scenario | Site | Heat waves (No of occurrences) | Extreme heat waves (No of occurrences) | Cold spells (No of occurrences) | Severe cold spells (No of occurrences) |
|---|---|---|---|---|---|
| Baseline (1950-1999) | Muela | <2 | <2 | 8 - 10 | 6 – 8 |
| | Sepinare | <2 | <2 | 8 - 10 | 8 – 10 |
| | Setibi | <2 | <2 | 8 - 10 | 8 – 10 |
| | Koporale | <2 | <2 | 8 - 10 | 8 – 10 |

**Table 3.2.4:** Summary of projected changes in heat waves and cold spells for the intermediate and more distant futures at each of the PCAs

| Scenario | Site | Heat waves (No of occurrences) | Extreme heat waves (No of occurrences) | Cold spells (No of occurrences) | Severe cold spells (No of occurrences) |
|---|---|---|---|---|---|
| Intermediate future | Muela | No change | No change | Decrease by >30% | Decrease by >30% |
| | Sepinare | No change | No change | Decrease by >30% | Decrease by >30% |
| | Setibi | No change | No change | Decrease by >30% | Decrease by >30% |
| | Koporale | No change | No change | Decrease by >30% | Decrease by >30% |
| More distant future | Muela | Not defined | No change | Decrease by >30% | Decrease by >30% |
| | Sepinare | Not defined | No change | Decrease by >30% | Decrease by >30% |
| | Setibi | Not defined | No change | Decrease by >30% | Decrease by >30% |
| | Koporale | Not defined | No change | Decrease by >30% | Decrease by >30% |

## Precipitation

Rainfall is the major driver of ecosystem and agrohydrological responses. The timing and amount of precipitation influences crop growth and determines the composition, distribution and abundance of natural vegetation. The amount, intensity and frequency of rainfall can all be calculated or measured (Knoesen *et al*., 2009). Mean annual precipitation provides an indication of the long-term quantity of water available to an area for hydrological and agricultural purposes (Schulze and Kunz, 2010d).

Historic information indicates that mean annual precipitation is in the order of 800 to 1000mm for Muela and 600 to 800mm for the remainder of the PCAs (Table 3.2.5). Mean annual precipitation is projected to increase across all case study areas. In the intermediate future, these increases could be in the order of 100 to 200mm but could increase by up to 300mm in the more distant future (Figure 3.2.4 and Table 3.2.6).

The distribution of rainfall within a year is evident in monthly rainfall values. Projections show that median precipitation is likely to increase in all cardinal months (January, April, July and October) in both the intermediate and more distant futures across all PCAs (Table 3.2.6). In the intermediate future, changes are likely to be most pronounced in winter and spring with increases in October in the order of a 30 to 100% (Figure 3.2.6) while increase in July may be more than 100% (Figure 3.2.5). In the more distant future, these changes are likely to persist however April precipitation is also projected to increase in the order of 30 to 100% (Figure 3.2.6).

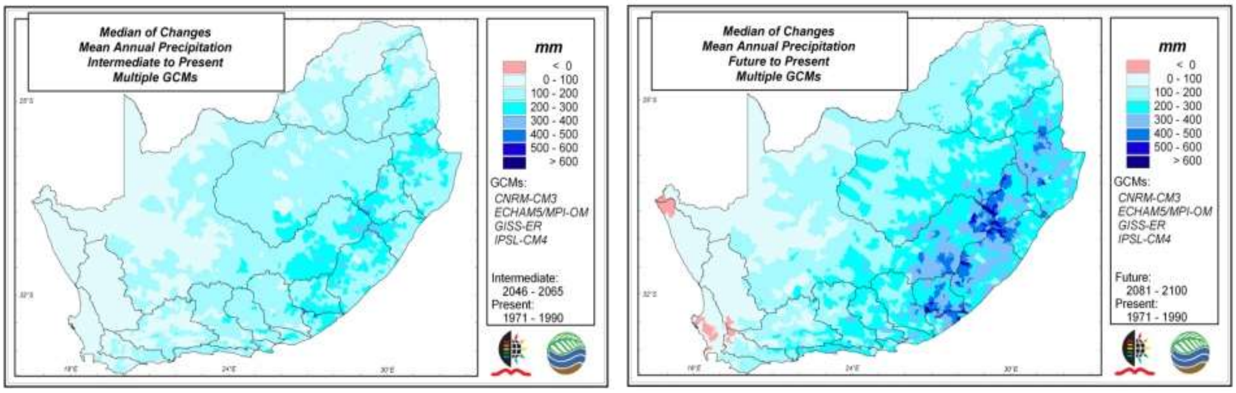



**Figure 3.2.4:** Median of changes in mean annual precipitation (mm) between the intermediate future and present (left), and the more distant future and present climate scenarios (right) for multiple GCMs (extracted from Schulze and Kunz, 2010d)

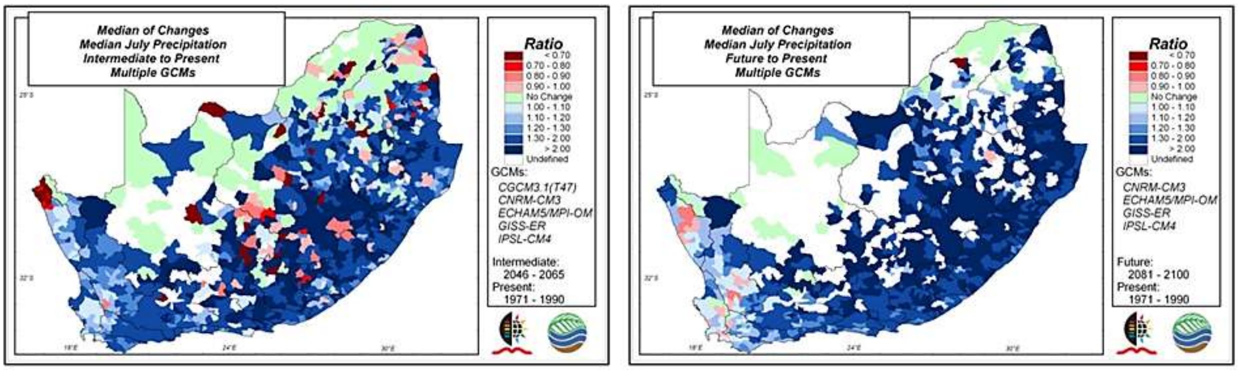



**Figure 3.2.5:** Median of ratio changes in July precipitation for the intermediate future to present (left) and more distant future to present scenarios (right) for multiple GCMs (Schulze and Kunz, 2010e)

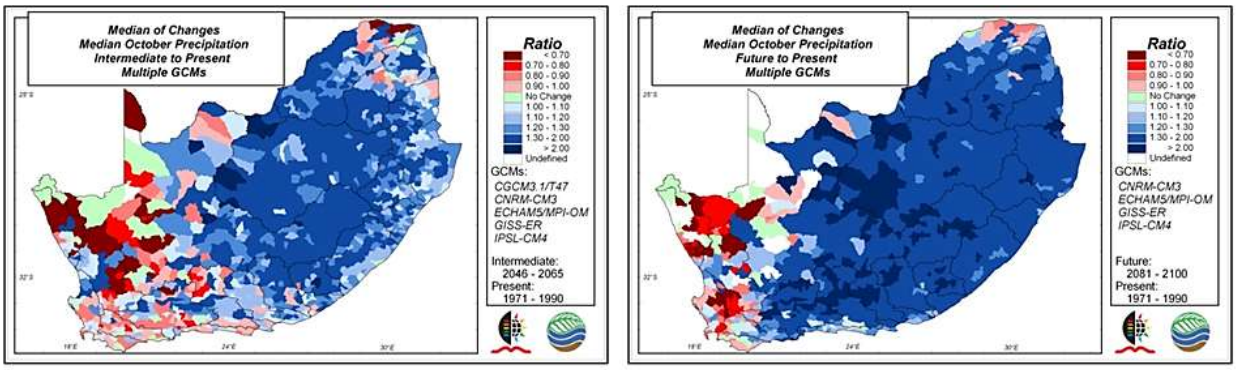



**Figure 3.2.6:** Median of ratio changes in October precipitation for the intermediate future to present (left) and more distant future to present scenarios (right) for multiple GCMs (extracted from Schulze and Kunz, 2010e)

**Table 3.2.5:** Summary of mean annual precipitation and median precipitation of the cardinal months for baseline (historical; 1950 - 1999) climatic conditions for each of the PCAs

| Scenario | Site | Mean Annual Precipitation (mm) | Median January Precipitation (mm) | Median April Precipitation (mm) | Median July Precipitation (mm) | Median October Precipitation (mm) |
|---|---|---|---|---|---|---|
| Baseline (1950 - 1999) | Muela | 800 - 1000 | 100 - 120 | 40 - 60 | <5 | 60 - 80 |
| | Sepinare | 600 - 800 | 100 - 120 | 20 - 40 | 5 - 10 | 60 - 80 |
| | Setibi | 600 - 800 | 100 - 120 | 20 - 40 | 5 - 10 | 60 - 80 |
| | Koporale | 600 - 800 | 100 - 120 | 40 - 60 | 5 - 10 | 60 - 80 |

**Table 3.2.6:** Summary of projected changes in mean annual precipitation and median precipitation of the cardinal months for the intermediate and more distant futures at each of the PCAs

| Scenario | Site | Median of changes Mean Annual Precipitation (mm) | Median of changes January Precipitation | Median of changes April Precipitation | Median of changes July Precipitation | Median of changes October Precipitation |
|---|---|---|---|---|---|---|
| Intermediate future | Muela | 100 - 200 | Increase by 10 – 20% | Increase by 30 – 100% | Increase by >100% | Increase by 30 – 100% |
| | Sepinare | 100 - 200 | Increase by 10 – 20% | Increase by 20 – 30% | Increase by >100% | Increase by 30 – 100% |
| | Setibi | 100 - 200 | Increase by 10 – 20% | Increase by 20 – 30% | Increase by >100% | Increase by 30 – 100% |
| | Koporale | 100 - 200 | Increase by 20 - 30% | Increase by 20 – 30% | Increase by >100% | Increase by 30 – 100% |
| More distant future | Muela | 200 - 300 | Increase by 10 - 20% | Increase by 30 – 100% | Increase by >100% | Increase by 30 – 100% |
| | Sepinare | 200 - 300 | Increase by 20 – 30% | Increase by 30 – 100% | Increase by >100% | Increase by 30 – 100% |
| | Setibi | 200 - 300 | Increase by 20 – 30% | Increase by 30 – 100% | Increase by >100% | Increase by 30 – 100% |
| | Koporale | 200 - 300 | Increase by 10 – 20% | Increase by 30 – 100% | Increase by >100% | Increase by 30 – 100% |

Average rainfall may be high or low, may be concentrated over short or longer periods and may vary between seasons. Rainfall concentration provides an indication of the spread of the rainy season over time. A rainfall concentration index is used to indicate this spread. A concentration index of 100% would imply that all of a location's rainfall falls in a very concentrated time period of one single month while a concentration index of 0% would mean that the rainfall in each month of the year is the same (Schulze and Kunz, 2010f). All PCAs show a more even distribution of rainfall across the months but with a reduction in summer rainfall (Table 3.2.8). However, while the average monthly rainfall may appear to be more evenly distributed the intensity of this rainfall may vary from baseline conditions.

Rainfall seasonality provides an indication of the dominant season in which the rainfalls. Rainfall seasonality regions in southern Africa include:

- early summer rainfall region (with rainfall concentration in December or earlier),
- mid-summer (peak concentration in January),
- late summer (February), and
- very late summer rainfall region (with peak concentration March to May) (Schulze and Kunz, 2010g).

Baseline climatic conditions indicate that all the PCAs have mid-summer rainfall (Table 3.2.7). However, this seasonality is likely to shift to that of late summer rainfall in both the intermediate and more distant futures at all PCAs (Table 3.2.8).

**Table 3.2.7:** Summary of rainfall concentration and seasonality for baseline (historical; 1950 - 1999) climatic conditions for each of the PCAs.

| Scenario | Site | Rainfall concentration | Rainfall seasonality |
|---|---|---|---|
| Baseline (1950 - 1999) | Muela | 50 - 55 | Mid-summer (January) |
| | Sepinare | 50 - 55 | Mid-summer (January) |
| | Setibi | 50 - 55 | Mid-summer (January) |
| | Koporale | 50 - 55 | Mid-summer (January) |

**Table 3.2.8:** Summary of projected changes in rainfall concentration and seasonality for the intermediate and more distant futures at each of the PCAs

| Scenario | Site | Rainfall concentration | Rainfall seasonality |
|---|---|---|---|
| Intermediate future | Muela | 45 – 50 | Late summer (February) |
| | Sepinare | 30 - 45 | Late summer (February) |
| | Setibi | 30 - 45 | Late summer (February) |
| | Koporale | 30 - 45 | Late summer (February) |
| More distant future | Muela | 30 - 45 | Late summer (February) |
| | Sepinare | 30 - 45 | Late summer (February) |
| | Setibi | 30 - 45 | Late summer (February) |
| | Koporale | 30 - 45 | Late summer (February) |

## Heat units and Chill units

Temperature affects the developmental rate of many organisms. Plants are dependent on the accumulation of mean temperatures above a certain threshold to develop from one point in their lifecycle to the next. The measure of accumulated heat is known as physiological time and is often expressed and approximated in degree days or heat units (Schulze and Kunz, 2010h).

Figure 3.2.7 shows differences between the future and present for accumulated summer heat units while Figure 3.2.8 shows differences between the future and present for accumulated winter heat units. Both data sets are derived from the 'middle-of-the-road' ECHAM5/MPI-OM GCM (Schulze and Kunz, 2010h) and use a base temperature of 10º. Baseline information indicates that the study areas currently experience less than 1200 degree days during summer and less than 200 degree days during winter (Table 3.2.9). The number of summer accumulated heat units at each of the case is projected to increase by 30 to 100% in the intermediate future and by more than 100% in the more distant future across all PCAs (Table 3.2.10). Similarly winter accumulated heat units are likely to increase by more than 100% in both the intermediate and more distant futures across all PCAs (Table 3.2.10).

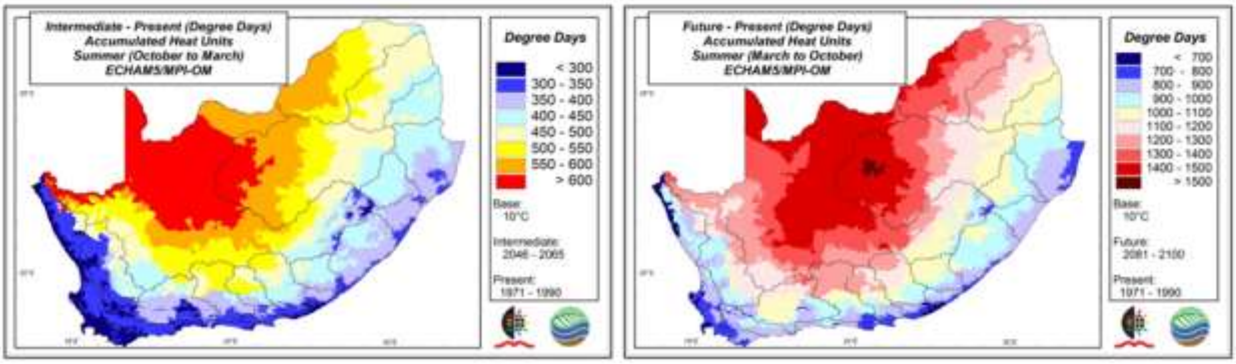



**Figure 3.2.7:** Differences in summer heat units for the intermediate future to present (left) and more distant future to present scenarios (right) for ECHAM5/MPI-OM GCM (extracted from Schulze and Kunz, 2010h)

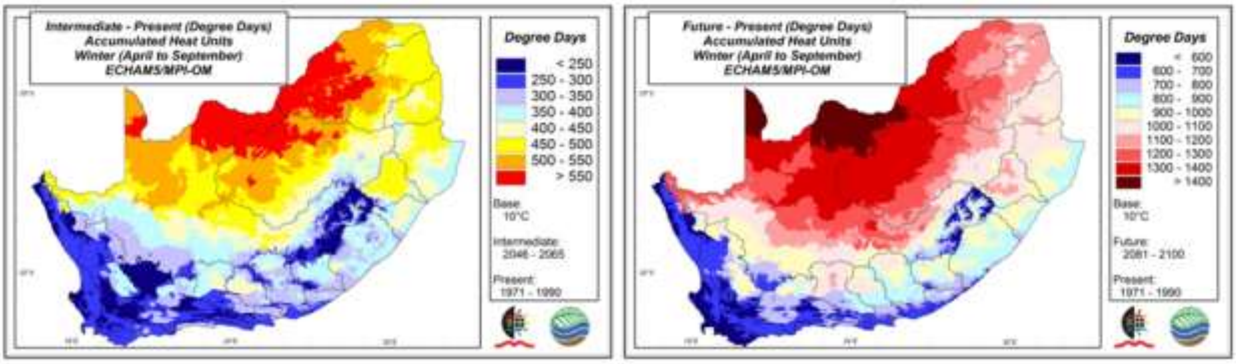



**Figure 3.2.8:** Differences in winter heat units for the intermediate future to present (left) and more distant future to present scenarios (right) for ECHAM5/MPI-OM GCM (extracted from Schulze and Kunz, 2010h)

Baseline information for positive chill units (extracted from Schulze and Kunz, 2010i) indicates that the study areas currently experience between 1250 and 1750 accumulated positive chill units. Not surprisingly, results from multiple GCMs (5 in the case of the intermediate future and 4 for the more distant future) project median reductions in ratios in the order of 0 – 20% in the intermediate future and by greater than 30% in the more distant future across all study sites.

**Table 3.2.9:** Summary of heat units and chill units for baseline (historical; 1950 - 1999) climatic conditions for each of the PCAs.

| Scenario | Site | Accumulated heat units Annual | Accumulated heat units Summer | Accumulated heat units Winter | Accumulated positive chill units Winter |
|---|---|---|---|---|---|
| Baseline (1950 - 1999) | Muela | 1000 - 1500 | <1200 | <200 | 1250 - 1500 |
| | Sepinare | 1000 - 1500 | <1200 | <200 | 1500 - 1750 |
| | Setibi | 1000 - 1500 | <1200 | <200 | 1500 - 1750 |
| | Koporale | 1000 - 1500 | <1200 | <200 | 1500 - 1750 |

**Table 3.2.10:** Summary of projected changes in heat units and chill units for the intermediate and more distant futures at each of the PCAs

| Scenario | Site | Accumulated heat units Annual | Accumulated heat units Summer | Accumulated heat units Winter | Accumulated positive chill units Winter |
|---|---|---|---|---|---|
| Intermed-iate future | Muela | Increase by 600 - 700 | Increase by 400 - 450 | Increase by 250 - 300 | -300 to -200 |
| | Sepinare | Increase by 600 - 700 | Increase by 400 - 450 | Increase by 250 - 300 | -300 to -200 |
| | Setibi | Increase by 600 - 700 | Increase by 400 - 450 | Increase by 250 - 300 | -300 to -200 |
| | Koporale | Increase by 600 - 700 | Increase by 400 - 450 | Increase by <250 | -300 to -200 |
| More distant future | Muela | Increase by 2000 - 2200 | Increase by 1000 - 1100 | Increase by 800 - 900 | < -700 |
| | Sepinare | Increase by 1600 - 1800 | Increase by 1000 - 1100 | Increase by 700 - 800 | < -700 |
| | Setibi | Increase by 1600 - 1800 | Increase by 1000 - 1100 | Increase by 700 - 800 | < -700 |
| | Koporale | Increase by 1600 - 1800 | Increase by 1000 - 1100 | Increase by 700 - 800 | < -700 |

## Evaporation

Increasing temperatures will have a significant impact on evaporation. The amount of water evaporated from the earth's atmosphere is known as actual evaporation while the amount of water evaporated from plants is referred to as transpiration. Various formulae have been developed to calculate the evaporation from crops. These formulae take into account variables which affect transpiration such as temperature, relative humidity and wind. Crop water use through transpiration indicates how much water is required from rain or irrigation for the crop to grow without being stressed (Schulze and Kunz, 2010j).

Baseline information indicates that mean annual reference crop evaporation rates are approximately 1400 to 1600mm across all PCAs (Table 3.2.11). These rates are likely to increase in both the intermediate and more distant futures (Figure 3.2.9). Projections from the ECHAM5/MPI-OM GCM indicate a 10 - 15% increase in the intermediate future and a 20 -25% increase in the more distant future across all PCAs (Table 3.2.12).

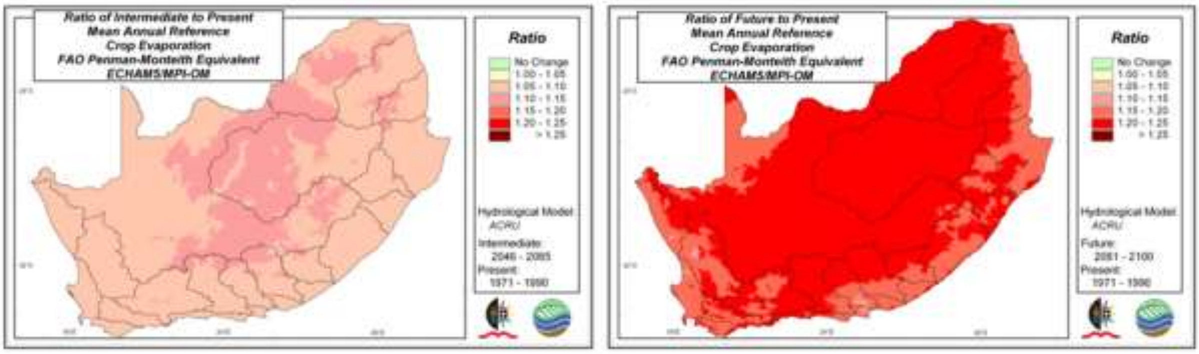



**Figure 3.2.9:** Ratios of intermediate future to present (left) and more distant future to present means of annual reference evaporation by the Penman-Monteith approach derived from output of the ECHAM5/MPI-OM GCM (extracted from Schulze and Kunz, 2010j)

**Table 3.2.11:** Summary of mean annual reference crop evaporation for baseline (historical; 1950 - 1999) climatic conditions for each of the PCAs.

| Scenario | Site | Mean annual reference crop evaporation (mm) |
|---|---|---|
| Baseline (1950 - 1999) | Muela | 1400 - 1600 |
| | Sepinare | 1400 - 1600 |
| | Setibi | 1400 - 1600 |
| | Koporale | 1400 - 1600 |

**Table 3.2.12**: Summary of projected changes in mean annual reference crop evaporation for the intermediate and more distant futures at each of the PCAs

| Scenario | Site | Mean annual reference crop evaporation (mm) |
|---|---|---|
| Intermediate future | Muela | 10 – 15% increase |
| | Sepinare | 10 – 15% increase |
| | Setibi | 10 – 15% increase |
| | Koporale | 10 – 15% increase |
| More distant future | Muela | 20 – 25% increase |
| | Sepinare | 20 – 25% increase |
| | Setibi | 20 – 25% increase |
| | Koporale | 20 – 25% increase |

## Soil water stress

Climatic factors interact in a variety of ways through the soil and affect the environment in which plants have to grow (Schulze and Kunz, 2010k). Changes in soil water content thus have direct implications for natural vegetation and crops.

Baseline information indicates that soil water stress is not an issue in the study areas with, on average, more than 120 days a year not experiencing any soil water stress. However, all study areas (except Muela) experience water logging an average of 5 to 20 days per year (Table 3.2.13).

While the results of the GCMs at a site level do vary slightly, general indications are that soil water stress is unlikely to be an issue in both the intermediate and more distant futures with reductions in the number of days experiencing both mild and severe water stress (Table 3.2.14). However, water logging is projected to increase by approximately 70 -100% at Sepinare and Ha Koporale in the intermediate future and by more than 100% at Muela and Ha Koporale in the more distant future (Table 3.2.14).

**Table 3.2.13:** Summary of water stress for baseline (historical; 1950 - 1999) climatic conditions for each of the PCAs

| Scenario | Site | No water stress (No of days) | Mild water stress (No of days) | Severe water stress (No of days) | Stress due to water logging (No of days) |
|---|---|---|---|---|---|
| Baseline (1950 – 1999) | Muela | >120 | >70 | <125 | 20 - 30 |
| | Sepinare | >120 | >70 | <125 | 5 - 20 |
| | Setibi | >120 | >70 | <125 | 5 - 20 |
| | Koporale | >120 | >70 | <125 | 5 - 20 |

**Table 3.2.14:** Summary of projected changes in water stress for the intermediate and more distant futures at each of the PCAs

| Scenario | Site | No water stress (No of days) | Mild water stress (No of days) | Severe water stress (No of days) | Stress due to water logging (No of days) |
|---|---|---|---|---|---|
| Intermediate future | Muela | Increase 0 – 10% | Decrease by 0 – 10% | Decrease by 10 – 20% | Increase by 70 – 100% |
| | Sepinare | Increase 10 – 20% | Increase by 0 -10% | Decrease by 10 – 20% | Decrease by 10 – 20% |
| | Setibi | Increase 10 – 20% | Increase by 0 -10% | Decrease by 10 – 20% | Decrease by 10 – 20% |
| | Koporale | Increase 10 – 20% | Decrease by 0 – 10% | Decrease by >30% | Increase by 70 – 100% |
| More distant future | Muela | Increase by 10 – 20% | Decrease by 20 – 30% | Decrease by >30% | Increase by >100% |
| | Sepinare | Increase by 10-20% | Decrease by 20 – 30% | Decrease by 0 – 10% | Increase by 30 – 70% |
| | Setibi | Increase by 10-20% | Decrease by 20 – 30% | Decrease by 0 – 10% | Increase by 30 – 70% |
| | Koporale | Increase by 30-70% | Decrease by >30% | Decrease by >30% | Increase by >100% |

## 3.3 Summary of anticipated changes in climate

A summary of the projected changes in selected climatic variables is provided for each PCA in Tables 3.3.1 – 3.3.4 below. Changes are likely to be similar across all PCAs. Mean annual temperatures are projected to rise, with increases being greater in the more distant future than in the intermediate future. These rising temperatures will have a profound effect on evaporation, with projections indicating a 10 - 15% increase in evaporation in the intermediate future and a 20 -25% increase in the more distant future. This in turn will affect the frequency and intensity of rainfall events. Mean annual precipitation is projected to increase in the order of 100 to 200mm in the intermediate future and by up to 300mm in the more distant future. Increase in precipitation in all four cardinal months is also anticipated. Rainfall seasonality is likely to shift from mid-summer (January) to late-summer

(February) and monthly rainfall is expected to be more evenly distributed but with a reduction in summer rainfall. These increases in precipitation will have a direct impact on soil moisture with an increase in water logging projected in both the intermediate and more distant futures.

**Table 3.3.1:** Summary of projected changes in climatic variables at Muela.

| Variable | Baseline | Intermediate future | More distant future |
|---|---|---|---|
| Mean annual temperature | 12 – 14 ºC | Increase by 2.0 – 2.5 ºC | 5.0 – 6.0 ºC |
| January maximum | 24 – 26 ºC | Increase by 2.0 – 2.5 ºC | 4.0 – 5.0 ºC |
| July minimum | -2 – 0 ºC | Increase by 2.0 – 2.5 ºC | 5.0 – 6.0 ºC |
| Heat waves | <2 occurrences | No change | Not defined |
| Extreme heat waves | <2 occurrences | No change | No change |
| Cold spells | 8 – 10 occurrences | Decrease by >30% | Decrease by >30% |
| Severe cold spells | 6 – 8 occurrences | Decrease by >30% | Decrease by >30% |
| Mean Annual Precipitation | 800 – 1000mm | Increase by 100 – 200mm | Increase by 200 - 300mm |
| Median January Precipitation | 100 – 120mm | Increase by 10 – 20% | Increase by 10 - 20% |
| Median April Precipitation | 40 – 60mm | Increase by 30 – 100% | Increase by 30 – 100% |
| Median July Precipitation | <5mm | Increase by >100% | Increase by >100% |
| Median October Precipitation | 60 – 80mm | Increase by 30 – 100% | Increase by 30 – 100% |
| Rainfall concentration | 50 - 55 | 45 – 50 | 30 - 45 |
| Rainfall seasonality | Mid-summer (January) | Late summer (February) | Late summer (February) |
| Accumulated heat units - Annual | 1000 - 1500 | Increase by 600 - 700 | Increase by 2000 - 2200 |
| Accumulated heat units - Summer | <1200 | Increase by 400 - 450 | Increase by 1000 - 1100 |
| Accumulated heat units - Winter | <200 | Increase by 250 - 300 | Increase by 800 - 900 |
| Accumulated chill units - Winter | 1250 - 1500 | -300 to -200 | < -700 |
| No water stress | >120 | Increase 0 – 10% | Increase by 10 – 20% |
| Mild water stress | >70 | Decrease by 0 – 10% | Decrease by 20 – 30% |
| Severe water stress | <125 | Decrease by 10 – 20% | Decrease by >30% |
| Water logging | 20 - 30 | Increase by 70 – 100% | Increase by >100% |

**Table 3.3.2**: Summary of projected changes in climatic variables at Sepinare

| Variable | Baseline | Intermediate future | More distant future |
|---|---|---|---|
| Mean annual temperature | 10 – 12 ºC | Increase by 2.0 – 2.5 ºC | Increase by 5.0 – 6.0 ºC |
| January maximum | 22 – 24 ºC | Increase by 2.0 – 2.5 ºC | Increase by 4.0 – 5.0 ºC |
| July minimum | < -2 ºC | Increase by 2.0 – 2.5 ºC | Increase by > 6.0 ºC |
| Heat waves | <2 occurrences | No change | Not defined |
| Extreme heat waves | <2 occurrences | No change | No change |
| Cold spells | 8 – 10 occurrences | Decrease by >30% | Decrease by >30% |
| Severe cold spells | 8 – 10 occurrences | Decrease by >30% | Decrease by >30% |
| Mean Annual Precipitation | 600 – 800mm | Increase by 100 – 200mm | Increase by 200 – 300mm |
| Median January Precipitation | 100 – 120mm | Increase by 10 – 20% | Increase by 20 – 30% |
| Median April Precipitation | 20 – 40mm | Increase by 20 – 30% | Increase by 30 – 100% |
| Median July Precipitation | 5 – 10mm | Increase by >100% | Increase by >100% |
| Median October Precipitation | 60 – 80mm | Increase by 30 – 100% | Increase by 30 – 100% |
| Rainfall concentration | 50 - 55 | 30 - 45 | 30 - 45 |
| Rainfall seasonality | Mid-summer (January) | Late summer (February) | Late summer (February) |
| Accumulated heat units - Annual | 1000 - 1500 | Increase by 600 - 700 | Increase by 1600 - 1800 |
| Accumulated heat units - Summer | <1200 | Increase by 400 - 450 | Increase by 1000 - 1100 |
| Accumulated heat units - Winter | <200 | Increase by 250 - 300 | Increase by 700 - 800 |
| Accumulated chill units - Winter | 1500 - 1750 | -300 to -200 | < -700 |
| No water stress | >120 | Increase 10 – 20% | Increase by 10-20% |
| Mild water stress | >70 | Increase by 0 -10% | Decrease by 20 – 30% |
| Severe water stress | <125 | Decrease by 10 – 20% | Decrease by 0 – 10% |
| Water logging | 5 - 20 | Decrease by 10 – 20% | Increase by 30 – 70% |

**Table 3.3.3:** Summary of projected changes in climatic variables at Setibi

| Variable | Baseline | Intermediate future | More distant future |
|---|---|---|---|
| Mean annual temperature | 10 – 12 ºC | Increase by 2.5 – 3.0 ºC | Increase by 5.0 – 6.0 ºC |
| January maximum | 20 – 22 ºC | Increase by 2.0 – 2.5 ºC | Increase by 4.0 – 5.0 ºC |
| July minimum | < -2 ºC | Increase by 2.0 – 2.5 ºC | Increase by > 6.0 ºC |
| Heat waves | <2 occurrences | No change | Not defined |
| Extreme heat waves | <2 occurrences | No change | No change |
| Cold spells | 8 – 10 occurrences | Decrease by >30% | Decrease by >30% |
| Severe cold spells | 8 – 10 occurrences | Decrease by >30% | Decrease by >30% |
| Mean Annual Precipitation | 600 – 800mm | Increase by 100 – 200mm | Increase by 200 – 300mm |
| Median January Precipitation | 100 – 120mm | Increase by 10 – 20% | Increase by 20 – 30% |
| Median April Precipitation | 20 – 40mm | Increase by 20 – 30% | Increase by 30 – 100% |
| Median July Precipitation | 5 – 10mm | Increase by >100% | Increase by >100% |
| Median October Precipitation | 60 – 80mm | Increase by 30 – 100% | Increase by 30 – 100% |
| Rainfall concentration | 50 - 55 | 30 - 45 | 30 - 45 |
| Rainfall seasonality | Mid-summer (January) | Late summer (February) | Late summer (February) |
| Accumulated heat units - Annual | 1000 - 1500 | Increase by 600 - 700 | Increase by 1600 - 1800 |
| Accumulated heat units - Summer | <1200 | Increase by 400 - 450 | Increase by 1000 - 1100 |
| Accumulated heat units - Winter | <200 | Increase by 250 - 300 | Increase by 700 - 800 |
| Accumulated chill units - Winter | 1500 - 1750 | -300 to -200 | < -700 |
| No water stress | >120 | Increase10 – 20% | Increase by 10-20% |
| Mild water stress | >70 | Increase by 0 -10% | Decrease by 20 – 30% |
| Severe water stress | <125 | Decrease by 10 – 20% | Decrease by 0 – 10% |
| Water logging | 5 - 20 | Decrease by 10 – 20% | Increase by 30 – 70% |

**Table 3.3.4:** Summary of projected changes in climatic variables at Ha Koprale

| Variable | Baseline | Intermediate future | More distant future |
|---|---|---|---|
| Mean annual temperature | 10 - 12 ºC | Increase by 2.5 – 3.0 ºC | Increase by 5.0 – 6.0 ºC |
| January maximum | 22 - 24 ºC | Increase by 2.0 – 2.5 ºC | Increase by 4.0 – 5.0 ºC |
| July minimum | < -2 ºC | Increase by 2.0 – 2.5 ºC | Increase by > 6.0 ºC |
| Heat waves | <2 occurrences | No change | Not defined |
| Extreme heat waves | <2 occurrences | No change | No change |
| Cold spells | 8 – 10 occurrences | Decrease by >30% | Decrease by >30% |
| Severe cold spells | 8 – 10 occurrences | Decrease by >30% | Decrease by >30% |
| Mean Annual Precipitation | 600 – 800mm | Increase by 100 – 200mm | Increase by 200 – 300mm |
| Median January Precipitation | 100 – 120mm | Increase by 20 - 30% | Increase by 10 – 20% |
| Median April Precipitation | 40 – 60mm | Increase by 20 – 30% | Increase by 30 – 100% |
| Median July Precipitation | 5 – 10mm | Increase by >100% | Increase by >100% |
| Median October Precipitation | 60 – 80mm | Increase by 30 – 100% | Increase by 30 – 100% |
| Rainfall concentration | 50 - 55 | 30 - 45 | 30 - 45 |
| Rainfall seasonality | Mid-summer (January) | Late summer (February) | Late summer (February) |
| Accumulated heat units - Annual | 1000 - 1500 | Increase by 600 - 700 | Increase by 1600 - 1800 |
| Accumulated heat units - Summer | <1200 | Increase by 400 - 450 | Increase by 1000 - 1100 |
| Accumulated heat units - Winter | <200 | Increase by <250 | Increase by 700 - 800 |
| Accumulated chill units - Winter | 1500 - 1750 | -300 to -200 | < -700 |
| No water stress | >120 | Increase 10 – 20% | Increase by 30-70% |
| Mild water stress | >70 | Decrease by 0 – 10% | Decrease by >30% |
| Severe water stress | <125 | Decrease by >30% | Decrease by >30% |
| Water logging | 5 - 20 | Increase by 70 – 100% | Increase by >100% |

# 4 IMPLICATIONS OF CLIMATE CHANGE ON ECOSYSTEM FUNCTIONING AND LIVELIHOODS

## 4.1 Impacts on ecosystem functioning

### Impacts on ecosystem functioning

The functioning of ecosystems is dependent on the linkages among organisms and their physical and biological environments. These linkages constitute a dynamic interaction within ever-changing systems (Millennium Ecosystem Assessment 2005). The complexity of ecosystems makes it extremely difficult to identify potential climate change impacts on ecosystem functionality. However, in order to identify adaptations to improve the resilience of livelihoods and to sustain ecosystem services in the Lesotho Highlands there is a need to attempt to provide an indication of the extent the impact climate change will have.

In addition to the potential impact of climate change, there is the well documented impact of unsustainable land management practice, such as overgrazing and over utilization of resources in the Lesotho Highlands (Quinlan, 1995; Chakela, 1999; Dejene, 2011). These anthropogenic impacts are likely the most important driving forces of change, and more specifically degradation, in the Lesotho Highlands. However, to try and establish the potential impact of climate change one needs to separate out the different impacts. Therefore, in this section we will discuss the potential impacts of climate change and in the following section (*Section 5*) anthropogenic impacts under different scenarios will be discussed, these will then be combined in the subsequent section (*Section 6*). Impacts of climate change will be considered on current conditions (i.e. evidence collected from recent studies undertaken at the pilot sites and from our own observations).

### Key climate and landscape variables

There are a wide range of variables that can be taken into consideration when looking at the impacts of climate change, however, the following were identified as the key variables that will likely have the greatest impact on ecosystem functionality in the Lesotho Highlands:

- Increased atmospheric carbon dioxide ($CO_2$) concentrations: The increase is likely the most important climate change variable because of the physiological effects increased $CO_2$ has on plants. These effects include:
    - Reduced transpiration, which allow plants to be more effective in retaining moisture;
    - Increased photosynthetic rates, where light, water and nutrients are not limiting; and
    - Relative photosynthetic rates for plants that have different metabolic pathways for carbon fixation in photosynthesis (i.e. 'C3' and 'C4'[4] plants).

[4] C3 and C4 plants have different modes of photosynthesis. The essential difference between the C3 and C4 modes of photosynthesis is that with high concentrations of $CO_2$ photosynthesis is generally higher in C3 plants. Alternatively, at low $CO_2$ concentrations and high temperatures photosynthesis is generally higher in C4 plants (Lattanzi, 2010).

- Increase in temperature: An increase in temperature places more stress on plants through the potential for greater moisture loss. In addition, C3 and C4 plants also respond differently to increased temperature and $CO_2$ concentrations (i.e. relative photosynthetic responses).
- Change in precipitation: The likely shift in seasonal rainfall, increased dry periods between rainfall events and increased intensity of rainfall events are particularly important when considering the growing season of both woody and herbaceous plants. This could have a significant impact on ecosystems should plants species not be able to adapt to the shift and changes in precipitation.
- Soil moisture stress: The increased duration of rainfall, i.e. the spreading of rainfall across seasons, is likely to result in an increased duration of soil saturation. However, the potential for increased soil saturation will only be significant where there is sufficient soil depth (i.e. predominantly within the low lying areas throughout the Highlands).
- Evaporation: An increase in evaporation will be of particular concern for areas of exposed substrate. Moisture loss from areas with poor basal cover is likely to be exacerbated by the increased evaporation, which could lead to increased soil erosion.

In addition to the key climate variables identified there is also a need to consider the variations in the landscape and how these affect ecosystems. These key variables include:

- Aspect and Slope: Permanent differences in amounts of radiant energy intercepted on contrasting exposures may cause marked variations not only in natural vegetation and on crop growth responses, but also in geomorphology, soil physical/chemical properties and hence soil moisture, snowmelt rates and streamflow (Schulze, 2011).

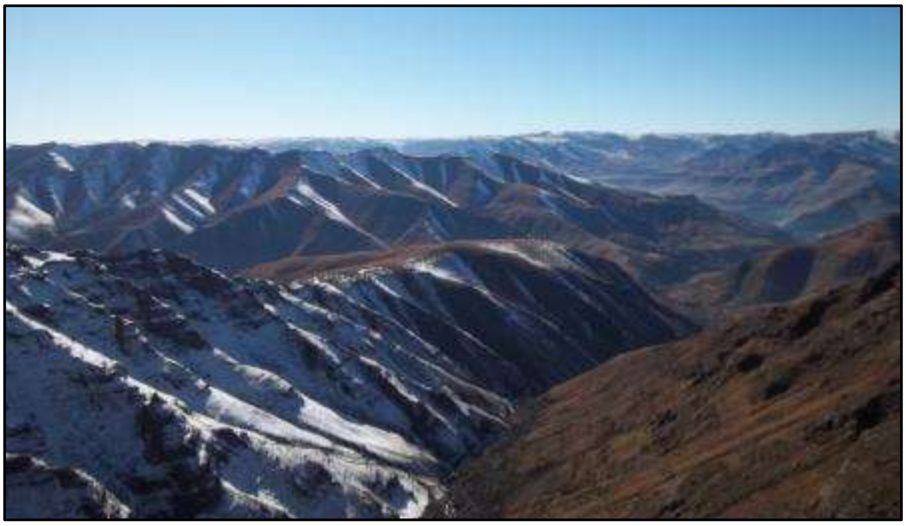


**Figure 4.1.1:** Illustration of the effect of aspect and slope within the mountainous terrain of the Lesotho Highlands

Energy budgets for incoming solar radiation on sloping terrain and associated differences in temperature and potential evaporation induced by differences in net radiation loadings on so-called 'warm' and 'cool' aspects were determined for the Katse, Mohale and Muela catchments.

**Table 4.1.1:** Shortwave solar radiation (MJ/m²/day) on cloudless days in mid-summer (21st December), the equinoxes (21st March; 21st September) and mid-winter (21st June) for latitude 29˚S in Lesotho for different slope gradients and aspects (Schulze, 2011)

| ASPECT | Horizontal | | | 10˚ | | | 20˚ | | | 30˚ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Facing) | Sum | Equ | Win | Sum | Equ | Win | Sum | Equ | Win | Sum | Equ | Win |
| North | 32.8 | 23.9 | 17.1 | 32.3 | 25.6 | 18.0 | 29.8 | 26.4 | 21.0 | 25.9 | 26.4 | 22.5 |
| NE/NW | 32.8 | 23.9 | 17.1 | 32.2 | 25.1 | 17.1 | 30.5 | 25.1 | 18.1 | 27.7 | 25.1 | 19.1 |
| East/West | 32.8 | 23.9 | 17.1 | 31.9 | 23.5 | 15.6 | 30.3 | 23.0 | 15.0 | 28.4 | 21.1 | 14.1 |
| SE/SW | 32.8 | 23.9 | 17.1 | 31.9 | 22.4 | 17.0 | 30.6 | 19.1 | 14.2 | 29.0 | 16.5 | 11.0 |
| South | 32.8 | 23.9 | 17.1 | 32.9 | 21.3 | 15.9 | 31.4 | 17.2 | 12.0 | 29.5 | 13.0 | 8.5 |

According to Schulze (2011), in mid-summer there are only relatively small differences in solar radiation receipt on different slope gradients and aspects. By the mid-season equinoxes for slopes up to 10˚ there is little difference on different aspects, with values around 24 MJ/m²/day. However, for steeper gradients the solar radiation on south facing aspects intercept only approximately half that of the north facing aspects. It is in mid-winter that the biggest differences in solar radiation loadings are evident. Again, the steeper the slope the greater the difference, with a 20˚ slope facing north receiving 75 % more radiation than a south facing slope of the same gradient, while in the case of a 30˚ slope a south facing slope receives only approximately 38 % of the solar energy that a north facing aspect does.

- Altitude: In generally there is a decrease in temperature with an increase in altitude. This change is generally reflected in the change in the distribution of vegetation communities along an altitudinal gradient. Therefore, the pilot sites were separated into four altitudinal zones, according to the broad changes in vegetation communities and landscape characteristics (SMEC, 2010). These included:
  - Maluti Foothills and Escarpment (1800m – 2100m)
  - Maluti Highlands (2100m – 2500m)
  - Sub-alpine Transition (2500m – 2900m)
  - Afro-alpine Grassland (> 2900m)

  The change in vegetation communities between the Maluti Highlands and the sub-alpine transition is less evident. However, distinct differences occur between the Maluti foothills and escarpment and the Maluti Highlands zone. Likewise there are also distinct differences between the sub-alpine transition and afro-alpine grassland zones. Examples include:
  - *Leucosidea* Shrubland and *Hyperrenhia* Grasslands, which largely only occur within the low lying areas of the Muela pilot site. This is the only site with a significant proportion below 2100m (i.e. Maluti foothills and escarpment); and
  - Alpine Grassland, which largely only occur above 2900m (i.e. within the Afro-alpine grassland zone).

  According to Schulze (2011a), the decrease in temperature with an increase in altitude, which is termed the temperature lapse rate and expressed as a decrease in °C per 1000 m, varies with the location of an area within the region, whether maximum or minimum temperatures are being assessed, with the month of the year and whether the location of interest is in a valley or exposed on a ridge. The lapse rates were determined for the Katse, Mohale and Muela catchments and there is a clear difference in lapse rates for minimum temperatures, which generally exceed those of maximum temperatures, with higher values in winter than in summer, and lapse rates of minimum temperatures in exposed locations are generally higher than in sheltered valley locations in winter months.

## Linking climate change variables to potential impacts on ecosystem services

Climate change is occurring on a global level and therefore impacts are generally only assessed at a very broad scale. Tackling the downscaling of climate change models to attempt to identify the impacts of climate change on ecosystem services within pilot sites in the Lesotho Highlands was achievable, however, at a relatively low confidence level. Even with a low confidence level it was still important to get an understanding of what is likely to happen to ecosystems, in order to focus on the most plausible adaptation measures to improve resilience.

With our current understanding of how the key climate change variables will likely impact on ecosystems, changes in vegetation communities throughout the pilot sites could only be hypothesized at a broad scale, i.e. the changes to the distribution of trees, shrubs and broad grassland communities. For this reason the vegetation communities (functional cover classes) identified from the original work undertaken for the ICM project (SMEC, 2010a) were further grouped into broader classes (Table 4.1.2). Projected changes are anticipated to take place at a species and community level, therefore only considering interaction at a broad community level was a simplification of the likely response to climate change, but one that was necessary in order to establish a potential trend.

**Table 4.1.2:** Broad vegetation communities used to determine the impacts of climate change on ecosystem functioning

| Broad Vegetation Communities / Land Cover Classes | Vegetation Communities / Land Cover Classes |
|---|---|
| Alpine Grassland | Alpine Grassland |
| Climax Grasslands | *Themeda-Festuca* Grasslands |
| | *Harpochloa* Grasslands |
| Croplands | Cultivation |
| Degraded Grasslands | *Aristida-Eragrostis-Artemesia* Degraded Grasslands |
| | *Hyparrenhia* Grasslands |
| Settlement & Infrastructure | Settlement & Infrastructure |
| Shrublands | *Felicia-Chrysocoma* Shrubland |
| | *Leucosidea* Shrubland |
| | Buddleia Shrubland |
| Trees | Trees (Poplar) |
| | Streambank Vegetation (Salix) |
| Wetlands | Wetlands |
| Other | Rocklands/Rocksheets |
| | Waterbodies |

The extent of the broad vegetation communities and land cover classes across all four of the pilot sites are illustrated in Figure 4.1.2 below.

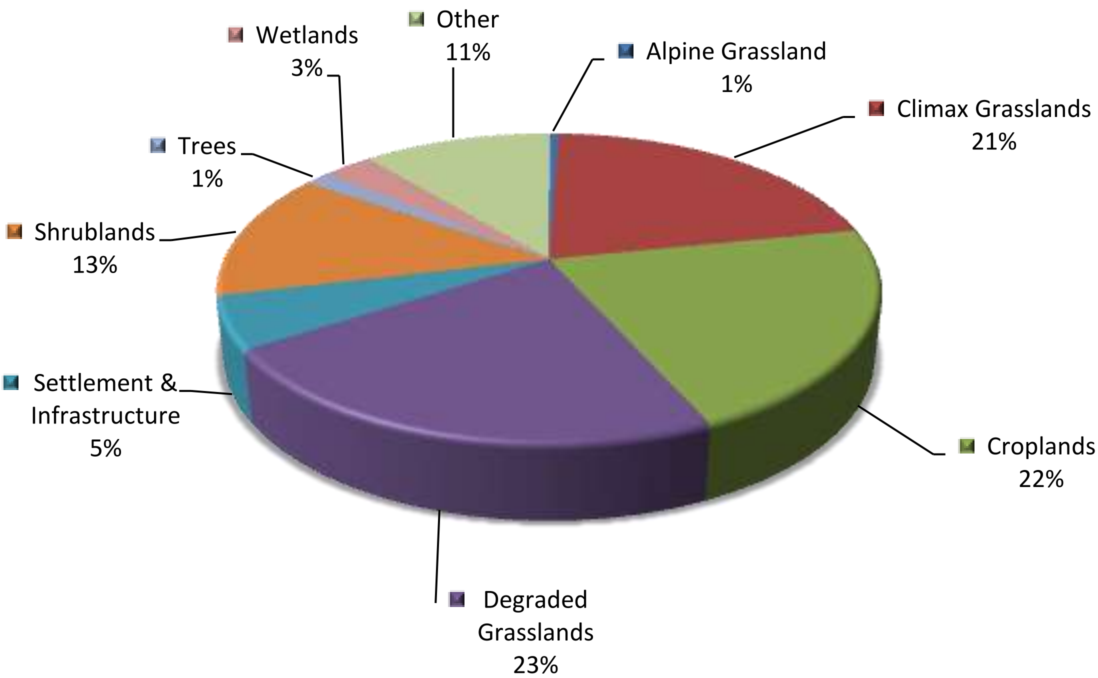



**Figure 4.1.2:** Distribution of the broad vegetation communities and land cover classes across all four pilot sites

The further grouping of vegetation communities also required the grouping of relative ecosystem services. The significance of the ecosystem services for each of the broad vegetation communities was determined by averaging the scores for each of the relevant vegetation communities originally assessed (Table 4.1.3).

**Table 4.1.3:** Ecosystem Services for broad vegetation communities and land cover classes throughout the pilot sites

| Current Ecosystem Services Supplied by the Broad Vegetation Communities and Land Cover Classes throughout the Pilot Sites | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Provisioning Services | | | | | | Supporting & Regulating Services | | | | | Cultural Services | |
| **Broad Vegetation Communities / Land Cover Classes** | **Grazing** | **Thatching** | **Fuel resources** | **Building materials** | **Medicine** | **Food production** | **Biodiversity** | **Erosion control** | **Sediment retention** | **Water supply** | **Streamflow Regulation** | **Recreational** | **Spiritual** |
| Alpine Grassland | High | None | None | None | High | None | High | High | Mod | High | High | None | High |
| Climax Grasslands | High | Low | None | None | Mod | Low | High | High | Mod | High | Mod | Mod | None |
| Degraded Grasslands | Mod | High | Mod | None | Low | None | Low | Low | Low | Low | Low | Mod | None |
| Shrublands | None | None | High | High | Mod | Low | Mod | High | Mod | None | None | Low | None |
| Wetlands | High | High | None | None | High | Low | High | High | High | High | High | Mod | None |
| Trees | Low | None | High | High | Mod | Low | Mod | High | Mod | Mod | Mod | High | Mod |
| Croplands | Low | Low | Low | None | None | High | None | None | None | None | None | None | None |
| Settlement & Infrastructure | Mod | Low | Low | None | Low | Mod | None | None | None | None | None | High | None |
| Other | None | None | None | None | Low | None | Low | Low | None | High | None | Low | None |

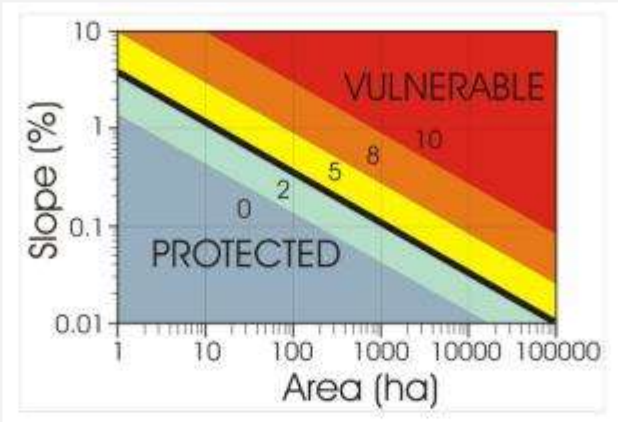
## Impacts of climate change

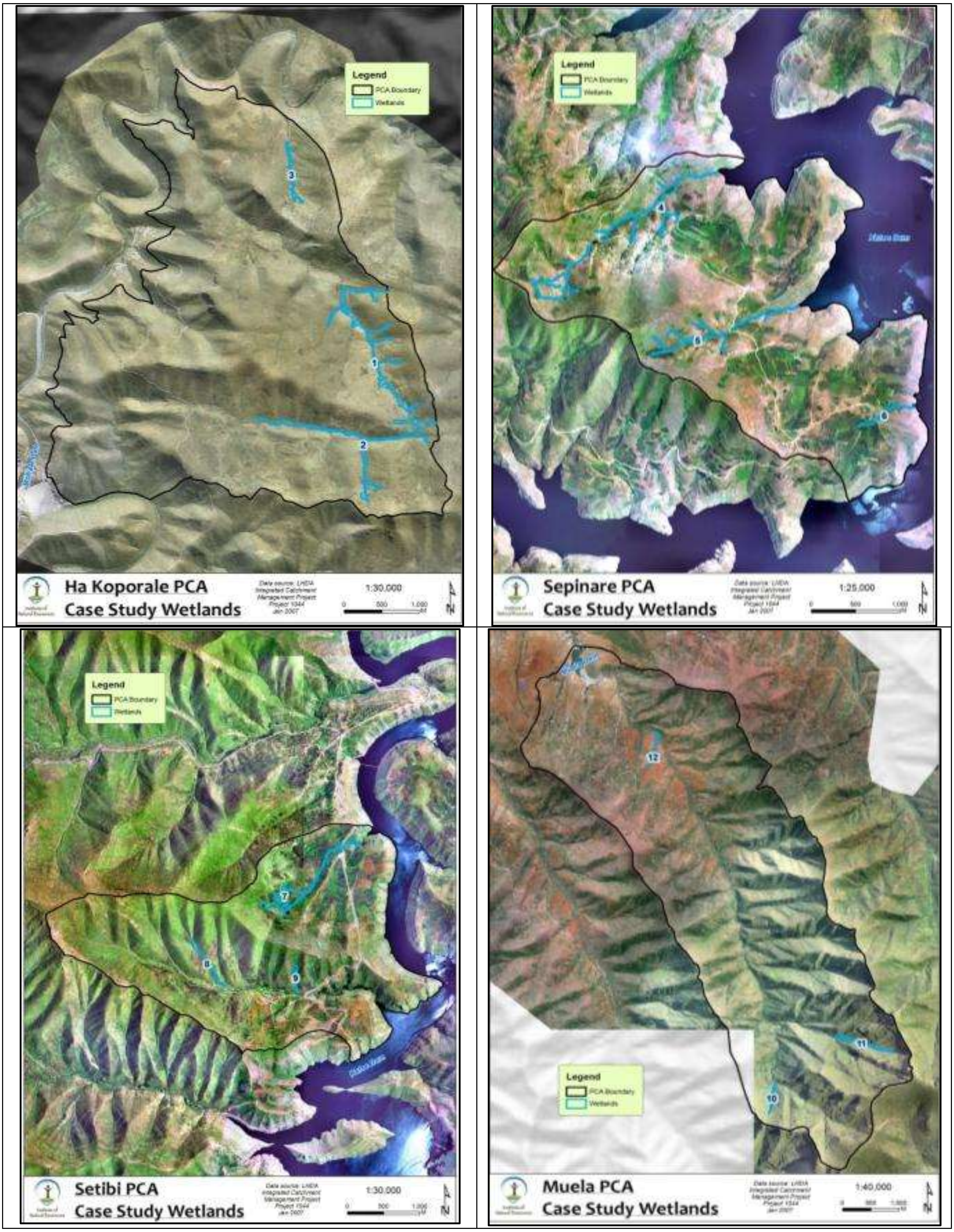
The key impacts of climate change on ecosystems within the four pilot sites will likely include:

- An increase in tree species within the lower altitudinal zones: Woody species that occur within the pilot sites are largely alien invasive species, with some indigenous species occurring within dense stands of shrubs in the low lying areas. The alien invasive species mostly included stands of poplar trees and willows along streambanks, but there are also a few smaller stands of Eucalyptus and Pinus species. These trees although introduced provided valuable provisioning services, particularly as fuel sources and for building material. The potential increase in $CO_2$ concentrations, increased temperature, and increased soil moisture saturation within the deeper soils of the low lying areas, will all benefit the growth of woody species. Considering the anticipated increase in suitability for theses tree species it is likely that there will be an increase in woody species throughout the lower lying altitudinal zones of the pilot sites (i.e. Maluti foothills and escarpment and the lower reaches of the Maluti Highlands). These findings are supported by the findings of Schulze (2010), where predicted increases in optimum growing areas for *Eucalyptus grandis*, *Pinus patula* and *Acacia mearnsii* were modelled, and all of these areas were shown to expand into the Lesotho Highlands.
- An increased distribution of shrubs: Similarly to the woody species both tall and short shrub species, examples include: *Leucosidea sericea, Buddleia salviifolia, Felicia filifola* and *Chrysocoma ciliate*, are projected to benefit from the increased $CO_2$ concentrations and increased temperature. The increased distribution of shrub species is likely to span across all four altitudinal zones, with different species potentially favouring conditions on slopes with varying aspects and at a range of altitudes. The increased favourable conditions for shrub species would also need to include a reduction in basal cover in areas currently occupied by dense swards of grass species, because without a 'foothold' shrubs will not be able to outcompete grass swards. The increase in shrubs across an altitudinal gradient for all four pilot sites and the consequences of this potential change will likely be one of the most important impacts on ecosystems as a result of climate change.
- An increase in C3 temperate grass species: As a general hypothesis plant communities respond to a general increase in temperature through a shift toward higher altitudes. While this will likely occur, the opposite is anticipated to occur when considering C3 temperate grass species (e.g. *Festuca caprina, Merxmuellera disticha,* etc.). There is a unique interaction between C4 sub-tropical grasses (namely *Themda triandra*) and C3 temperate grasses (namely *Festuca caprina*) between the sub-alpine transition and the Afro-alpine grassland altitudinal zones. These grasses utilize different modes of photosynthesis and with the predicted increase in $CO_2$ concentrations and temperature it is anticipated that C3 temperate grasses are likely to benefit more than C4 sub-tropical grasses.
- A loss of wetland functionality: The increased $CO_2$ concentrations, increased temperature and increased soil moisture saturation will likely benefit wetland plant species such as *Kniphofia caulescens*. However, the benefit to a range of wetland plant species is anticipated to be overshadowed by the potential effect an increased intensity in rainfall events is likely to have on the majority of wetlands throughout the pilot sites. Considering existing conditions of wetlands and the surrounding catchments it is likely that more intensive rainfall events will lead to an increase in sediment deposition within the wetlands or water bodies in the catchment. Increased sediment will potentially provide terrestrial species, such

as the increasing shrub layer with an opportunity to encroach into wetlands. In addition, this could be exacerbated where ice rats occur adjacent to wetlands, i.e. their burrowing activity could result in further ‘drying out’ of the wetlands. The primary reason for the potential for increased sedimentation is because of the vulnerability of the wetlands to erosion (Table 4.1.4 and Figure 4.1.3).

**Table 4.1.4:** Examples of wetlands within the four pilot sites and their vulnerability to erosion

| Wetland No. | Pilot Site | Area (Ha) | Slope % | Wetland vulnerability to incision of valley-bottom wetlands based on the relationship between longitudinal slope and area (Macfarlane *et al.*, 2009) |
|---|---|---|---|---|
| 1 | Koporale | 14.1 | 5.21 |   |
| 2 | Koporale | 12 | 9.26 | |
| 3 | Koporale | 2.7 | **10.73** | |
| 4 | Sepinare | 11.03 | **14.16** | |
| 5 | Sepinare | 6.2 | **19.59** | |
| 6 | Sepinare | 2.3 | 9.75 | |
| 7 | Setibi | 9.5 | **14.01** | |
| 8 | Setibi | 2.9 | **17.58** | |
| 9 | Setibi | 1.1 | **36.50** | |
| 10 | Muela | 1.5 | **44.52** | |
| 11 | Muela | 3.8 | **35.60** | |
| 12 | Muela | 1.6 | 9.01 | |




**<u>Figure 4.1.3:</u>** Selection of wetlands from all four pilot sites assessed for the vulnerability to increased erosion due to intensive rainfall events

- A loss of biodiversity, with particular concern for the loss of endemic species in high lying areas: The Lesotho alpine area is characterised by a high level of plant endemism (Chakela, 1999; Ministry of Natural Resources, 2000), and because of this it is important to highlight the projected vegetation response to climate change even though only a limited area from all four pilot sites falls within the alpine region (i.e. a small portion of the Muela site). In assessing the projected vegetation response impacts on faunal distributions will be addressed indirectly, as vegetation dynamics will determine future distributions of habitats for terrestrial species.

  On a global scale, plant life at high elevations is primarily constrained by direct and indirect effects of low temperature and perhaps also by reduced partial pressure of $CO_2$ (Schneider *et al*., 2007). Plants respond to these climatological influences through a number of morphological and physiological adjustments, such as stunted growth forms and small leaves, low thermal requirements for basic life functions, and reproductive strategies that avoid the risk associated with early life phases (Schneider *et al*., 2007). It has been well documented that projected changes in global temperatures and local precipitation patterns could significantly alter the altitudinal ranges of important species within existing mountain belts and create additional environmental stresses on already fragile mountain ecosystems (Guisan *et al.*, 1995; Schneider *et al*., 2007).

  There may be an argument for climate change benefiting plant species surviving at high altitudes. Through the increase of $CO_2$ concentrations and temperature, one may argue that these projected changes may reduce stress on vegetation communities adapted to harsh conditions. However, this hypothesis has not been substantiated and even if conditions did become more favourable there is a strong possibility of competition from species migrating to the area, which could result in the indirect loss of endemic species. It is therefore likely that the projected changes will have a negative impact on endemic species within the high lying areas of the Lesotho Highlands, either directly or indirectly.

Table 4.1.5 below identifies the effect the projected key impacts of climate change are anticipated to have on ecosystem services supplied by the vegetation communities throughout the pilot sites.

**Table 4.1.5:** Projected impacts of climate change on ecosystem services for broad vegetation communities

| Potential Impact of Climate Change on Ecosystem Services throughout the four pilot sites | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Broad Vegetation Communities / Land Cover Classes** | **Provisioning Services** | | | | | | **Supporting & Regulating Services** | | | | | **Cultural Services** | |
| | **Grazing** | **Thatching** | **Fuel wood** | **Building materials** | **Medicine** | **Food production** | **Biodiversity** | **Erosion control** | **Sediment retention** | **Water supply** | **Streamflow Regulation** | **Recreational** | **Spiritual** |
| Alpine Grassland | ↑↑ | | | | ↓↓ | | ↓↓ | | | | | | ↓ |
| Climax Grasslands | ↓↓ | | | | ↓ | | ↓ | ↓↓ | ↓↓ | ↓↓ | ↓↓ | | |
| Degraded Grasslands | ↓ | ↑↑↑ | ↑↑↑ | | ↑ | | | ↑ | ↑ | ↑ | ↑ | | |
| Shrublands | | | ↑↑↑ | ↑↑↑ | ↑ | | | | | | | | |
| Wetlands | ↓↓ | ↓↓↓ | | | ↓↓ | | ↓ | ↓↓↓ | ↓↓ | ↓↓↓ | ↓↓ | | |
| Trees | | | ↑↑↑ | ↑↑↑ | | | | | | ↓ | ↓ | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Slight Increase | ↑ | Slight Decrease | ↓ | **Moderate Increase** | ↑↑ | Moderate Decrease | ↓↓ |
| Significant Increase | ↑↑↑ | Significant Decrease | ↓↓↓ | **Unchanged** | | | |

** Note: these projected changes to ecosystem services are at a broad level and may vary slightly when projecting the change to ecosystem services at individual pilot sites.*

It needs to be stressed that these projected impacts of climate change do not take into consideration major driving forces such as species interaction, fire and on-going anthropogenic activities (such as overgrazing and over harvesting). In terms of species interaction, Suttle *et al. (*2007) argue that predictions of ecological response to climate change are based largely on direct climatic effects on species, and that species interactions can strongly influence responses to changing climate, even overturning direct climatic effects. The role of fire in determining the distribution of vegetation communities in southern Africa has long been debated, however, it is generally accepted that it plays an important role in shaping the vegetation of the higher rainfall eastern parts of South Africa, which includes the Lesotho Highlands (Bond *et al*., 2003). The extent of overgrazing on the rangelands and prohibited use of fire by local chiefs may potentially limit the impact of fire. However, the 'unauthorized' use of fire by herdsman, overgrazing and over utilization all have a major impact on species compositions within the different vegetation communities. These anthropogenic impacts, coupled with the impact of climate change, will be discussed in Section 6.

## Projected change to ecosystem services at the pilot sites

The primary aim of assessing the impacts of climate change was to establish the projected changes to vegetation communities throughout the four pilot sites and how these changes will likely impact on ecosystem services. A simplified approach was taken to assess how vegetation communities and individual plant species will likely respond to climate change. However, this approach does provide an indication of the trend climate change impacts are likely to have on ecosystem services. Refer to Appendix D for illustrations of the projected change in vegetation cover, at Muela and Sepinare, as a result of climate change. For consistence purposes only three of the pilot sites were assessed, namely Muela, Sepinare and Setibi. The findings from these sites will be extrapolated for Koporale.

#### *4.1.1.1 Impact of climate change at Muela*

Taking into consideration the projected impacts of climate change across the Lesotho Highlands the likely changes in ecosystem services supplied by the vegetation communities in the Muela pilot site include (illustrated in Figure 4.1.4):

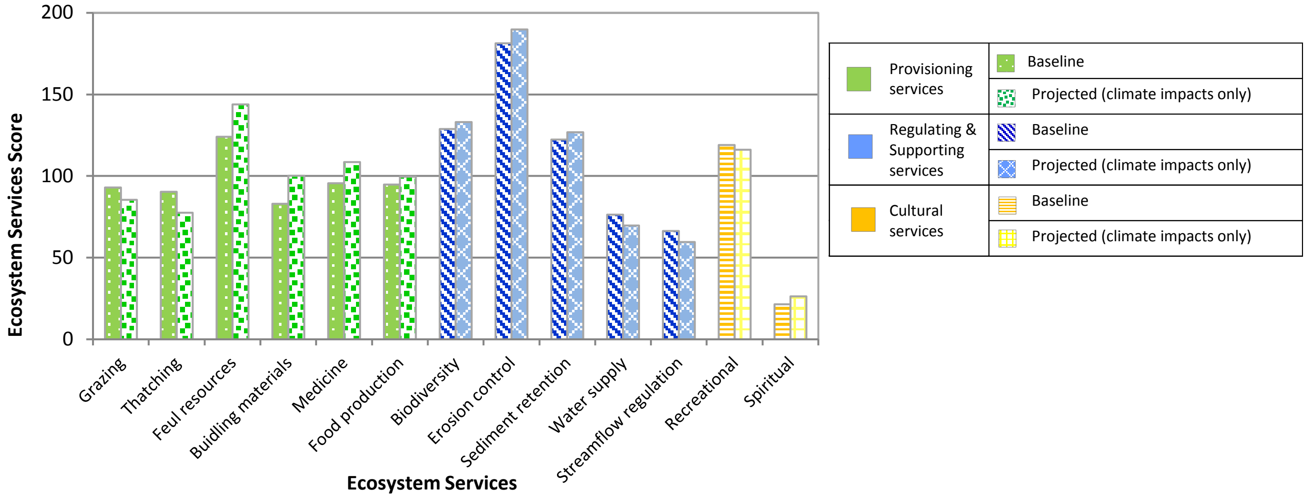



**Figure 4.1.4:** Comparison of baseline ecosystem services and projected changes to ecosystem services as a result of climate change for Muela

- A slight decrease in the provisioning services of grazing and thatching a result of a decrease in both climax and degraded grasslands. Alpine grasslands may increase slightly due to C3 temperate grasses benefiting from the increased $CO_2$ (~10%), however, this increase will likely only buffer the overall loss of grazing, which is likely why only a slight decrease is projected.
- Fuel resources and building material will likely be the provisioning services that show the most significant increases. This will be because of the projected increase in trees and shrubs. Trees are projected to increase by as much as 150-200%, whereas Leucosidea shrubland and *Felicia-Chrysocoma* shrublands are projected to increase by 20-30% and 30-40% respectively. The increase in shrubs is also the reason for a projected increase in 'medicine', however, this should be interpreted with caution as it indicates the medicinal benefits of a few shrubs species only. A general loss of medicinal plants throughout the pilot site may likely be a more accurate projection.
- The slight increase in food production(a 0-5% increase is projected) is indicative of the projected decrease in degraded grasslands, which generally have a low potential for food production. This should also be interpreted with caution as the degraded areas will like be replaced with trees and shrubs.
- An increase in biodiversity, erosion control and sediment retention is unlikely to be significant, where respective increases are in the range of 1-5%.

- A slight decrease in water supply and streamflow regulation can also be attributed to the projected increase in trees and shrubs, which would reduce grasslands that aid in regulating the supply of water. In addition, increases in invasive tree species will likely results in an increased water demand.
- Changes to cultural services are unlikely to be significantly affected by climate change.

#### ***4.1.1.2 Impact of climate change at Sepinare***

Projected changes as a result of climate change to ecosystem services for Sepinare include (illustrated in Figure 4.1.5).

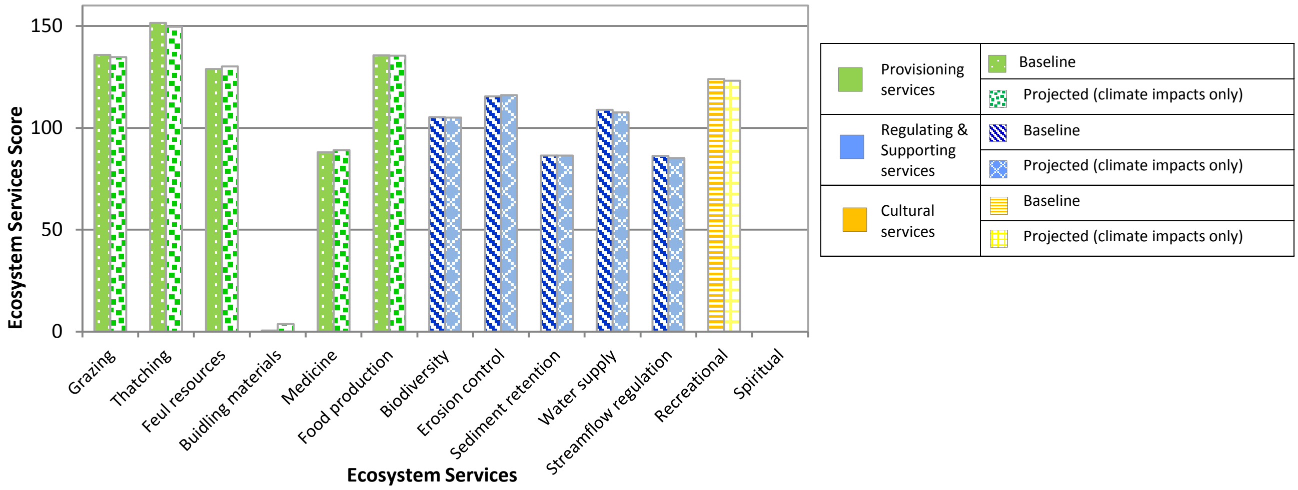



**Figure 4.1.5:** Comparison of baseline ecosystem services and projected changes to ecosystem services as a result of climate change for Sepinare

- A slight decrease in grazing would likely be from a projected increase in shrublands and trees. Sepinare is situated below the alpine zone and therefore unlikely to benefit significantly from a projected increase in temperate grass species.
- Thatching is anticipated to decrease slightly, which would likely be the result of a loss of degraded grassland (i.e. *Artemesia* is used for thatching) and some wetlands (*Merxmuellera macowanii* is used for thatching). However, this loss is unlikely to result in a significant change in the supply of thatching. The slight increase in fuel resources will likely be because of the projected increase in trees and shrubs. This may have been underestimated as dominant shrubland communities were not identified but a range of shrub species do occur throughout the degraded grasslands, which are the dominant vegetation communities throughout the pilot site.
- Although not clearly indicated in Figure 4.1.5, the increase in building material is projected to be the most significant increase, as stands of trees are projected to increase in the region of 500-600%.
- The projected slight increase in medicinal plants is indicative of the increase in trees and shrubs. Again this may be misleading as it only represents the medicinal value of these plants. Overall it is likely that a loss in medicinal plants would occur. The decrease in food production is indicative of the increase in shrubs and trees, however, this projected change would be unlikely because of the demand for cultivated land.

- No significant loss to biodiversity is anticipated.
- Supporting and regulating services are anticipated to decease slightly but not significantly, except perhaps for sediment retention and water supply, which would largely be because of the loss of wetland functionality. Changes to cultural services are unlikely to be significantly affected by climate change.

#### *4.1.1.3 Impact of climate change at Setibi*

Data for Setibi is still being analyzed and will be made available as soon as analysis is completed.

## 4.2 Impacts on agriculture

In recent times there has been an apparent increase in the frequency, magnitude and duration of climate shocks in Lesotho, with little or no time for recovery between shocks and increasingly erratic and variable rainfall (Midgley *et al*., 2011; Mosenene, 1999).

In addition to this, there is increased demand for arable land due to increasing population. This is expressed as households cultivating new lands on steep slopes with shallow, erodible soils and low agricultural potential. As a result, there is increased competition for land between crops and livestock, characterised by less resting of land (arable and grazing) and dwindling soil and water resources. With few opportunities for off-farm income and deepening of poverty, communities are less and less able to deal with additional climate shocks (Midgley *et al*., 2011). Consequently, short term climate variability can have serious impacts on crop and animal production. The degree of the impact of this variability on livelihoods is affected by the socio-economic status of the affected communities. In the case of poor highland communities, the impact of such climate variability is likely to be high.

### Modeled maize yield changes based on climate change scenarios

Two key production parameters as far as agricultural production is concerned are temperature and rainfall.

- Temperature is an important factor in photosynthesis. Photosynthetic activity in a plant starts at around 5$^{o}$C and increases steadily to an optimum temperature of 30-35$^{o}$C, after which photosynthetic activity declines. Thus longer a plant is exposed to optimum temperatures, the greater amount of photosynthesis, and hence plant growth, occurs.
- Plants absorb water from the soil and transpire this as water vapour through the leaves. With sufficient water available in the soil, plants can open their stomata (pores) to exchange carbon dioxide, which is required to form carbohydrates from photosynthesis. Water is also necessary for a variety of metabolic processes and the translocation of nutrient in the plant.

As a result, these two parameters are key determinants of plant growth and hence crop yields. The climate change models indicate that both temperature and rainfall in the Highlands are expected to increase, which should have a positive impact on crop production and animal production.

To illustrate these effects, a simple crop yield prediction model was used for the predicted climatic scenarios. Smith's (2006) yield prediction model uses a number of parameters to predict yields of various crops that are grown in southern Africa. Considering that maize makes up 80% of the land cultivated in Lesotho, this crop was used to model the expected yields under the different scenarios. The key parameters for the model are described below:

- **Rainfall**: The amount and distribution of rainfall has a great bearing on crop production. Effective rainfall is the amount of rainfall that is available to the plant and excludes rainfall that is lost to surface runoff or water that percolates into the soil out of reach of plant roots. The effectiveness of rainfall above 1000mm reduces progressively as this amount of water exceeds the rate at which plants can transpire water, while effective rainfall decreases with decreasing rainfall due to the erratic nature of low rainfall.
- **Temperature**: Indicates the energy status of the environment and determines the rate of growth of a plant. The temperature requirements of crops are best described as heat units, which describe the amount of time a plant is exposed to temperatures that promote growth. A heat unit is described as the average daily temperature above which crop growth will occur, added for the whole crop season. For example, in Maize, crops growth is considered to stop at temperatures below 10$^{o}$C so if the mean temperature for the day is 18$^{o}$C, the crop will accumulate 18-10 = 8 heat units for that day.
- **Soil**: Soil texture and effective rooting depth are important factors that determine the availability of moisture to plants. Soil texture refers to the relative proportions of sand silt and clay in the soil. Sandy soils hold less moisture, while loamy soils (less than 35% clay) generally are best for holding water that is available to plants. Clay soils (>35% clay)are often subject to waterlogging and drainage problems. Effective rooting depth refers to the depth that plant roots can penetrate the soil. Three main factors that limit effective rooting depth are impervious layers (clay, rock), a high water table, and acidic sub soils.
- **Management**: Smith (2006) notes that management entails the correct use of natural resources and tying together the various aspects of production in the right order, at the right time and right way to achieve high yields. These aspects include selecting the best seed varieties, appropriate plant population, balanced soil fertility and weed, pest and disease control.

Each of these factors (apart from management)is determined individually, based on the climatic and physical characteristics of the production area. Baseline rainfall and temperature data was obtained from The South African Atlas of Climatology and Agrohydrology (Schulze *et al*, 1997). Future changes in rainfall and temperature were calculated using the climate change scenarios. Effective soil depth and texture was determined using SMEC's (2010a) field data. For the purposes of this modeling exercise, an intermediate soil depth of 750mm was used throughout (all soils described in the SMEC report were characterised as Clay Loams). The management factor could not be determined directly, but was instead adjusted according to the reported maize yields for the area against the expected maize yields from the model. To start with, the management factor was set to 0.5, which is considered by Smith to be below average management. Initial results of this modeling exercise are provided in Table 4.2.1 below.

**Table 4.2.1:** Modeled maize yields under current climate conditions, with below average management

| | Muela | Setibi | Sepinare | Koporale |
|---|---|---|---|---|
| Effective rainfall | 640.8 | 580.7 | 497.9 | 401.0 |
| Heat Unit factor-Maize | 0.85 | 0.80 | 0.85 | 0.80 |
| Soil factor (750mm) | 0.9 | 0.9 | 0.8 | 0.8 |
| Management Factor | 0.5 | 0.5 | 0.5 | 0.5 |
| **MODELED YIELD (t/ha)** | 2.5 | 2.1 | 1.7 | 1.3 |
| **REPORTED YIELD RANGE (t/ha)** | 0.4-0.75 | 0.4-0.75 | 0.4-0.75 | 0.4-0.75 |

This indicates the importance of rainfall as a driver of production. The modeled yields were highest for Muela, with the highest effective rainfall and lowest for Koporale, which had the lowest rainfall. However, the modeled yields were significantly higher than the reported yields, even with the management factor set to 0.5 (considered by Smith to be below average management). Consequently, the management factor was reduced to 0.2 to align the modeled and reported yields (Table 4.2.2).

**Table 4.2.2:** Modeled yields with reduced management factor

| | Muela | Setibi | Sepinare | Koporale |
|---|---|---|---|---|
| Effective rainfall | 640.8 | 580.7 | 497.9 | 401.0 |
| Heat Unit factor-Maize | 0.85 | 0.80 | 0.85 | 0.80 |
| Soil factor (750mm) | 0.9 | 0.9 | 0.8 | 0.8 |
| Management Factor | 0.2 | 0.2 | 0.2 | 0.2 |
| **MODELED YIELD (t/ha)** | 1.0 | 0.8 | 0.7 | 0.5 |
| **REPORTED YIELD RANGE (t/ha)** | 0.5 | 0.5 | 0.5 | 0.5 |

This highlights that management is a very important factor that needs to be considered in any interventions that are applied to enhance resilience to climate change and agriculture. Using three management factors (0.2, 0.3 and 0.4) of 0.2, yields were modeled for the intermediate and more distant future climate scenarios for the PCAs. The results of this are provided in Table 4.2.3.

**Table 4.2.3:** Modeled yields of climate scenarios with different management levels

| Scenario | Management level | Modelled yield (t/ha) | | | |
|---|---|---|---|---|---|
| | | Muela | Setibi | Sepinare | Koporale |
| Present | Very Low (0.2) | 0.98 | 0.84 | 0.68 | 0.51 |
| | Low (0.3) | 1.47 | 1.25 | 1.02 | 0.77 |
| | Below average (0.4) | 1.96 | 1.67 | 1.35 | 1.03 |
| Intermediate future | Very Low (0.2) | 1.61 | 1.41 | 1.34 | 1.13 |
| | Low (0.3) | 2.41 | 2.12 | 2.00 | 1.70 |
| | Below average (0.4) | 3.21 | 2.83 | 2.67 | 2.26 |
| Distant future | Very Low (0.2) | 1.53 | 1.59 | 1.37 | 1.33 |
| | Low (0.3) | 2.29 | 2.38 | 2.06 | 1.99 |
| | Below average (0.4) | 3.05 | 3.18 | 2.74 | 2.65 |

While it is recognised that this yield model is a relatively simple and linear type of crop model, it does highlight that in the long term, assuming that crop production factors (i.e. management) remain constant, there will, on average, be an overall increase in crop yields. The climate change models concur with this in that they indicate an overall increase in net primary productivity, which is a measure of the photosynthetic rate of a plant. What this model also highlights is the very low current level of management associated with maize production in the Highlands and that interventions to enhance management of crops will enhance food security and reduce vulnerability to climate change.

However, most models are unable to account for some of the predicted changes in the climate. These are:

- ***Later onset of the rainy season***. The later onset of the rainy season and the shift from a mid-summer to late summer rainfall will effectively shorten the growing season. While the temperatures will be warm enough for production in October and November, crops will only be able to be planted with the onset of rain. In late summer and autumn, there will be sufficient rain, however temperatures will not be warm enough to sustain crop production, even when the predicted warmer temperatures are factored in.

- ***Changes in rainfall distribution and concentration***. The climate change models predict an increase in short duration, high intensity rainfall events (i.e. storms), with fewer long duration, low intensity rainfall events (gentle rain). The models also predict increased time between rainfall events. This means that while rainfall will increase overall, the intensity and distribution of the rainfall can place crop production at risk for the following reasons.
    - There is an increased risk of soil erosion and flash flooding
    - Effective rainfall is decreased as the intensity of the rainfall becomes greater than the soils infiltration rate, and water is lost as runoff.
    - The dry spells between rainfall events may come at critical stages of crop production (e.g. germination or tasseling in the case of maize).

- ***Higher evaporative demand***. With higher temperatures and more wind, the atmospheric evaporative demand will increase. When there is sufficient soil moisture, this will not have serious implications for crop production. The higher evaporative demand will mean that soils will dry out more quickly and the onset of plant water stress will be faster during dry spells.

- ***Increased incidence of plant stress due to waterlogging***. Waterlogged soils have low concentrations of oxygen (anaerobic), which is necessary for root metabolic activity. The climate change models predict an increase in the incidence of plant stress due to waterlogging. While this can be problematic in flat, valley bottom croplands with poor drainage, waterlogging is unlikely to pose a serious threat in the highland croplands because the soils are generally well drained and are on sloping land.

- ***Higher incidences of pests and disease.*** While the cool summers in the Highlands do limit crop production, the extremely cold winters prevent pests and diseases that are common in the lowlands. With warming temperatures, the climate will be more favourable to the incidence and spread of pests and diseases.

These factors all contribute to a higher risk of yield reduction and even crop loss. As indicated at the beginning of this section, there is a long history of climate variability in southern Africa and Lesotho, with a recent increase in the frequency, magnitude and duration of climate shocks leaving little time for recovery between events. In the face of predicted changes in climate under current crop production systems, the climate and livelihood shocks are likely to be greater and more frequent. Under these circumstances a severe drought may lead to complete crop failure.

## Livestock effects

Sufficiency of water supplies for livestock in the Highlands, particularly in late autumn and spring is expected to be problematic in future climate scenarios. The climate models show a trend towards delayed onset of spring rains with rainfall peaks moving from mid-summer to late summer. During spring droughts, livestock will have to be driven further when streams near settlements and cattle posts dry up. A lack of grazing along these routes can lead to increased mortality rates, especially for spring lambs (Midgley *et al.,* 2011). Rangelands persistently affected by drought and late onset summer rains will not produce sufficient feed and nutrients to maintain animal production and increasing variability in rainfall will exacerbate these problems. In addition to having to travel further to stock watering points, animals' water requirements will also increase with increasing temperature.

The greatest direct effect of the climate change on livestock is in the availability of feed resources. These are expected to decrease, if current high stocking rates are not reduced. Indirect effects of reduced feed resources on livestock production include:

- Lowered livestock productivity (reproduction, milk, meat, wool)
- Reduced carrying capacity of rangelands
- Reduced buffering capacity (resilience) of rangelands
- Reduced quality of grazing material
- Higher incidences of disease

Rising $CO_2$ concentrations are reported to be likely to 'fertilise' rangeland plants and provide increased growth however the extent to which these benefits will be realised are quite small (Schulze, pers comm. 2011) or will be offset by the increased frequency and intensity of wildfires resulting from increased woody growth. The increase in $CO_2$ concentration and warmer temperatures, compounded by continued overgrazing is likely to result in increased invasion by shrubs such as *Chrysocoma* (Midgley *et al*., 2011).

## Discussion

Mountain regions are already highly exposed to natural climate variability within and between seasons. Projected changes in climate indicate that this natural variability will intensify and the incidences of extreme events will increase. While temperature and rainfall are expected to increase, rainfall will be characterised by more extreme short duration intense events interspersed with drier periods. Given these changes, exacerbated by severe land degradation in rangelands and croplands, reliance largely on maize, limited state support to agriculture and reliance on rain fed agriculture and further compounded by socio-economic challenges of poverty, high population densities and HIV/AIDS, the impact of climate change is likely to be severe.

It is widely acknowledged that farmers with the least resources are the most vulnerable to climate change. Highland pastoralists in Lesotho are extremely vulnerable to climate change, but at the same time have always been coping with natural climate variability. It is necessary to build on this knowledge and identify interventions that are locally relevant and build on existing knowledge. Increasing food security and decreasing vulnerability requires an holistic approach that targets technical, social, economic and environmental issues and are integrated into policy and implementation at a national, regional, local and community scale.

## 4.3 Impacts of climate change on livelihoods

Households in the Highlands have to date managed to cope with climate variability. However for resource dependent households, such as those in the Highlands, climate change will represent significant disturbances and threats to their traditional livelihood strategies (Thomas *et al.,* 2005). Climate change is likely to bring about more permanent changes in local conditions (as opposed to variation), and incorporate more frequent and sudden extreme events. These changes will have harmful consequences for households' livelihood strategies that, depending on their adaptive capacity, will likely increase vulnerability and erode the livelihood systems of households in the Highlands. These impacts are likely to be experienced in two ways:

- Households ability to support themselves through their current livelihood strategies
- Health and well-being of individuals and the communities within which they live

### Impacts to livelihood strategies

Households' livelihoods are founded on two main fundamental strategies (i) agricultural production (crop and livestock production), and (ii) harvesting of natural resources (e.g. fuel materials, building materials, fruits and foods as well as fodder for livestock). While other strategies (such as welfare support, home based enterprises, remittances, etc.) do play an important role, households are centrally resource dependent. They rely on their own ability to farm crops and livestock, and to access natural resources from the wild to meet their daily survival needs and to maintain their resilience to shocks and extreme events.

As described in Section 4.1 above, under current conditions, there will be some impacts of climate change on ecosystem functioning and the generation of provisioning, regulating and supporting services. Land use and environmental management will increasingly focus on maximization of agricultural production, and trade-offs in ecosystem services likely to be made with prioritization of provisioning services at the expense of the other ecosystem services. However the impacts of climate change will likely result in a shift in provisioning services, with benefits becoming seasonal rather than year round. Maximisation of benefits from provisioning services will result in loss of certain key habitat types which will mean that regulating and supporting services will decline significantly. The decline in these services undermines ecosystem functioning which in the long run has a knock on effect by undermining provisioning services. This will result in a gradual deterioration in the potential of the environment to support the needs of the resource dependent households. This will therefore have fundamental negative consequences for households' crop production and livestock farming operations, as well as their ability to harvest sufficient natural resources from the wild to meet current requirements.

The consequence of these trends is likely to be a shrinking of returns from households farming and resource harvesting operations. This will result in increasing dependence on non-resource based opportunities (e.g. home based enterprises, remittances, and welfare grants) to generate cash incomes, which households would need to purchase essential foods and goods. However, given the very limited market and employment opportunities in the Highlands, it is unlikely that households will be able to proportionately increase these cash incomes to compensate for the decline in agricultural and resource harvesting yields. This will result in escalation in the already high poverty levels, further erosion in the resilience of livelihoods, and a decline in households' ability to sustain themselves.

## Impacts to health and social well-being

There is no evidence to suggest that climate change in Lesotho Highlands will directly increase or create new health risks associated with the spread of disease vectors such as malaria. However, the negative impacts to livelihood strategies will have health impacts such as increased risk of malnutrition especially among children, and increased health risk associated with deficient diets.

Any increase in extreme events, such as flood and snow events, will also have health consequences for households for whom it will become increasingly difficult to ensure warm and dry living conditions. This would increase the risk of illnesses such as influenza, bronchitis and pneumonia. This will have a knock-on effect for households, with affected family members unable to assist with chores and responsibilities particularly crops and livestock production. This could further compound household food security and well-being risks.

If the shrinking livelihood opportunities scenario (described in 4.3.1 above) materializes and households' ability to meet food security needs are eroded, there will be increasing pressure on family members to migrate and search for alternative income opportunities. This may involve adult and children in the family. This would result in a breakdown in family structure and community cohesion, with a likely increase in the trend of old and frail and very young family members remaining in the Highlands and becoming increasingly vulnerable as more and more able bodied community members leave the Highlands in search of better opportunities.

Children will increasingly be compelled to leave school in order to assist with taking over chores and farming responsibilities of absent family (who migrate in search of work), thereby further eroding the skills and capacity base within these communities, which in turn has consequences for adaptation capacity and resilience.

## Discussion

Households' ability to continue sustaining themselves will likely depend on the severity of the climate and environmental changes, and their ability to cope and adapt to these changes. However in all likelihood, there would be an increase in dependence on welfare and external aid.

# 5 IMPLICATIONS OF LIKELY FUTURE SCENARIOS ON ECOSYSTEM FUNCTIONING AND LIVELIHOODS

## 5.1 Tortoise Scenario

### Summary of key attributes of the scenario

| |
|---|
| **POSITIVE**<br>Population growth rate decreases to zero and does not drive increasing resource use pressure.<br>Overall pressure on the environment continues to grow driven by need to meet the survival requirements of households living in poverty.<br>Strong and fair governance systems and social cohesion<br>Good governance, sound planning systems and an equitable and fair society.<br>Secure tenure and property rights.<br>Reasonable levels of infrastructure development and service delivery.<br>Social cohesion and the equitable society contribute to regulated use of natural - particularly improved management of the commons and open access resources.<br>Collective responsibility and actions to overcome environmental degradation- but effectiveness of efforts limited due to poverty and lack of skills and resources.<br>Expansion of residential areas limited to existing settlements rather than sprawl to new areas. |
| **NEGATIVE**<br>Ineffective policy/policy vacuum real developmental and environmental challenges not addressed.<br>Shortage of technology/lack of finance - inhibits economic diversification - a single agricultural sector economy.<br>Lack of economic development - widespread poverty.<br>Lack of skills and finance restricts households' ability to move beyond primary agriculture.<br>Livestock remain a key livelihood strategy - but households driven to maximise the quantity rather than quality of herds.<br>Livestock pressure and lack of policy - rangeland condition not optimised for animal production or biodiversity.<br>Households dependent on cropping for food security - lack of skills and finance limits ability to diversify crops or increase yields.<br>Increasing land use pressure for expanding cropping areas.<br>Settlements are moderately to poorly serviced - increased environmental pressures and negative impacts such as pollution. |
| **CONCLUSION**<br>Increased anthropogenic pressures on the environment will result in biodiversity loss and environmental degradation, which may struggle to recover even though population growth will stabilise in long term. |

### Impacts on ecosystem functioning[5]

Under this scenario households are highly dependent on livestock and cropping, however strong social cohesion and equitable society contributes to commitment to the regulated use of natural resources. Although grazing plans are drafted and herd sizes are regulated, these requirements are not fully implemented because of poverty and lack of skills and resources. This control results in a slight improvement in rangeland condition, particularly in respect of the *Eragrostis, Themeda* and *Harpochloa* communities however the cultivation of Capability Classes I, II, III, IV, V and VI to meet

[5] As explained in Section 2.1, no recent imagery was available for the Ha-Koporale Pilot Site and thus this site has been excluded from these assessments. However given the similarity of the Ha-Koporale site to the other 3 pilot sites, similar trends and changes in ecosystem services are anticipated.

food security requirements still results in a significant decline in ecosystem services. Good governance limits the cultivation of Classes VII and VIII which stabilizes the supply of both provisioning and regulating services albeit at a very low level.

The *Themeda-Festuca* grasslands play a critical role in the supply of both provisioning and regulating services across all three sites but particularly at Sepinare and Setibi (Appendix E, Figures E1 and E3). The loss of the *Themeda-Festuca* grasslands under the Tortoise scenario is likely to have the greatest impact at Sepinare. Currently there is a large area of this vegetation community present; however with increased cropping this vegetation community will decrease significantly resulting in a corresponding decline in provisioning, regulating and supporting services In addition, the other vegetation communities at this site are also likely to decline dramatically and thus ecosystem functioning at Sepinare is likely to be severely threatened under this scenario. Muela has a diverse array of ecosystems and while the contribution of some of these communities to the overall supply of ecosystem services may be reduced, the impact of this scenario is not as severe as at the other sites.

While cropping is set to increase, food production is unlikely to be as high as illustrated in Figures 5.1.1, 5.1.2 and 5.1.3 as the condition of the production areas will decrease and high poverty levels will limit inputs and management. Thus an overall decline in food production could be expected in the long term. Similarly, under this scenario large tracts of grassland and shrubland are converted to cultivation which may provide some additional fodder and grazing but only in the winter months. It is important to note that this shift in supply of this service will be seasonal with stover only available during the winter months compared to grasslands which were available year round. This is therefore still likely to negatively impact on overall stocking capacity.

Importantly, there is likely to be a significant decline in regulating and supporting services although these services will still persist but at greatly reduced levels. The impact of the reduction in regulating and supporting services is likely to be greatest at Sepinare (Figure 5.1.3).

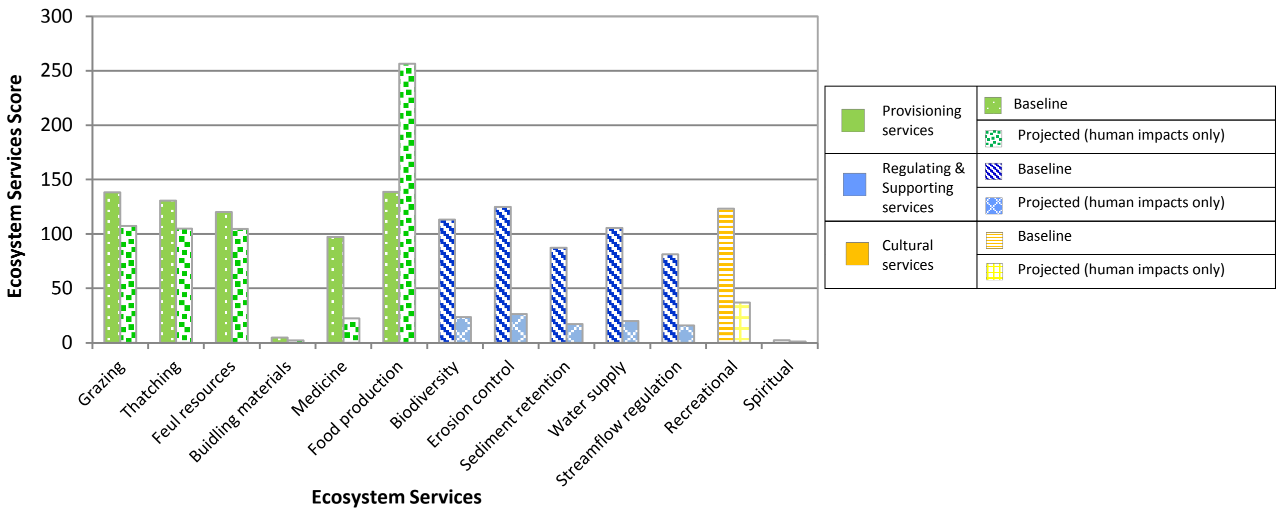



**Figure 5.1.1:** Projected change in ecosystem services at Setibi under the Tortoise Scenario

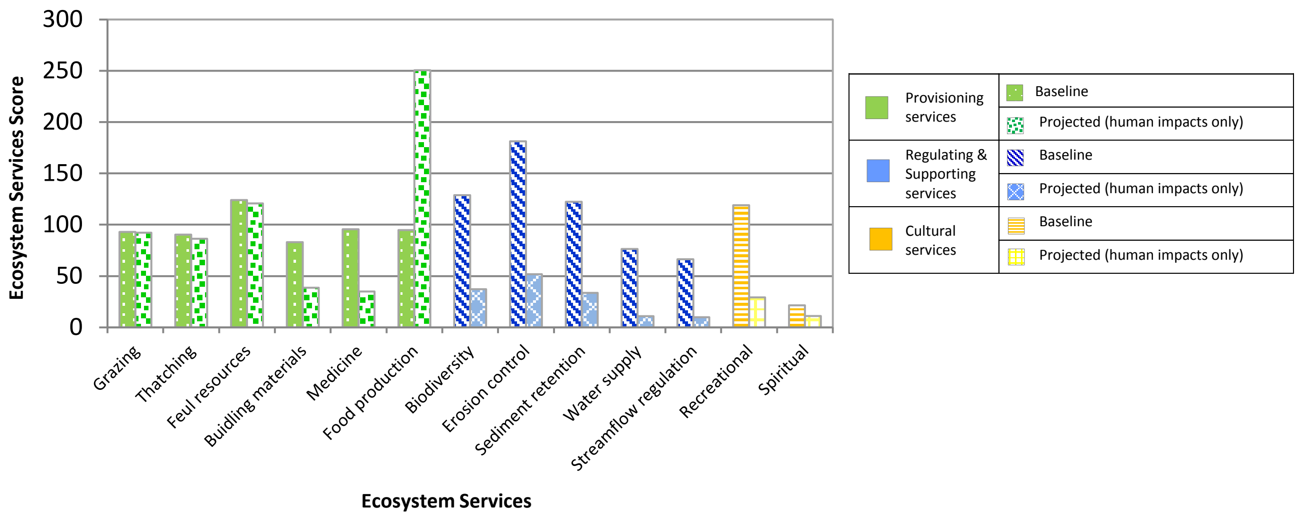



**Figure 5.1.2:** Projected change in ecosystem services at Muela under the Tortoise Scenario

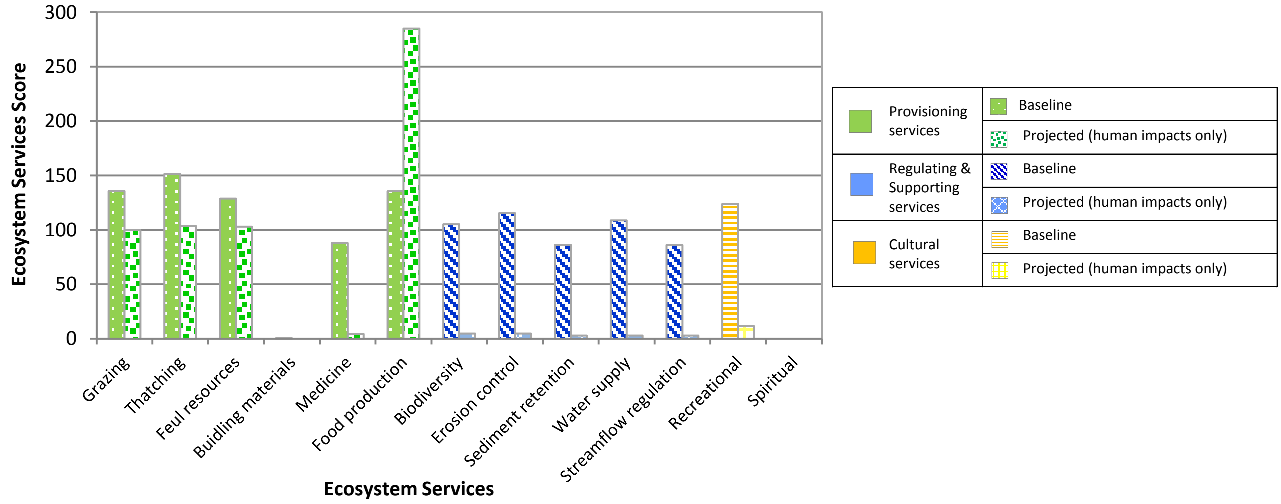



**Figure 5.1.3:** Projected change in ecosystem services at Sepinare under the Tortoise Scenario

## Impacts on agriculture[6]

Subsistence agriculture remains the dominant form of agriculture across all four pilot sites, as there are limited opportunities for diversified economies due to a lack of appropriate technology and access to finance. Pressure on the cropping resources and grazing resources remain high and improved systems for production are poorly developed.

However due to good governance and social cohesion, cropping resources are well protected from erosion and further degradation by improved soil conservation measures. This slows down degradation of arable lands, but does not halt or reverse it. A lack of diversity in crops being produced remains the norm although some improved practices such as conservation tillage are promoted and adopted by some farmers. With no investment in new agricultural technologies or the use of inputs, crop production declines slowly.

[6] Given that agricultural production practices and potential do not differ significantly across the four pilot community areas, no distinction has been made in the likely implications of future scenarios on agricultural production at any of the villages

Overstocking with livestock continues, although herd sizes and movements are more closely monitored. Excessively large flocks of small livestock owned by individuals are discouraged and herd sizes reflect the improved equity between households. The quality of the livestock however remains poor and there is little investment in genetic improvement and animal vigour remains low. Stock numbers are reduced slightly, but not to the extent that an improvement in grazing occurs, resulting in a continued decline in rangeland resources, particularly in the cattle posts.

## Livelihood trajectories and trade-offs[7]

Limited capital investment and appropriate new technologies or farming systems translate into little or no development, and poverty levels remain relatively high. Households therefore continue to struggle to meet livelihood needs and rely primarily on agricultural production. The land use focus therefore remains on maximizing benefits from the ecosystem's provisioning services, such as agriculture and resource harvesting, as these are seen as the most effective ways of meeting livelihood needs and addressing poverty in the short term. However, land use management decisions to maximize the benefits from provisioning services result in trade-offs. Maximizing agricultural production is achieved in exchange for habitat loss (e.g. *Themeda-Festuca* grasslands) and a gradual deterioration in ecosystem functioning. This undermines the sustainability of the benefits from regulating, supporting and cultural services, which ultimately. Therefore, while yields from crop production and livestock numbers are maximized in the short term, a gradual decrease in nutrient cycling, increase in soil erosion, loss of soil water retention potential etc. which results in declining agricultural yields in the medium to long term. This will finally exacerbate poverty levels by undermining households' ability to meet livelihood needs through agricultural and resource harvesting practices.

Households do however collaborate and act collectively in planning and managing crop lands and rangelands, and therefore the environmental degradation is slow and gradual. Ecosystem functioning is threatened and the loss of regulating and supporting services is inevitable if this scenario persists.

Good social cohesion and strong social structures and networks mean that there is an equitable distribution of benefits and a collective sense of responsibility does exist. This translates into the opportunity for interventions for improved environmental management. However any improvement in local environmental conditions and economic development will likely need to be driven from a national.

[7] Livelihood strategies and vulnerabilities do not differ significantly across the four pilot community areas and therefore no distinction has been made in the likely implications of future scenarios on livelihoods at specific villages.

## 5.2 Rabbit Scenario

### Summary of key scenario attributes

| |
|---|
| **POSITIVE** |
| Structured stable society and diversified economy - access to finance and capital for investment |
| Strong and fair governance systems - enabling policy environment and long term planning horizons |
| Access to land fair/equitable with secure tenure |
| Investment in education - improved skills levels |
| Improved skills, access to technology and financing - improvement in the quality and productivity of farming |
| Livestock improvement increases returns from herds - reduces the dependence large herd sizes |
| Good governance and control of grazing - overall improvement in rangeland condition |
| Investment, skills and technologies enhance crop production, diversification and yields |
| Good governance and enforcement restricts expansion of cropping areas to suitable cropping areas |
| Diversification in local economy – and local value adding opportunities - improved economic returns from livestock and crop production – reduced poverty and households are less vulnerable |
| Improvements in planning, services, infrastructure in settlements - limits negative environmental impact |
| Controlled use of communal resources and reduced poverty levels - reduce pressure on natural resources |
| Social cohesion, governance and planning - community efforts to address environmental degradation |
| **NEGATIVE** |
| Poverty, despite being low, still motivates poorest households to maximise herd sizes and crop production areas as a livelihoods resilience strategy |
| Positive population growth rates in the longer term – continues to increase pressure on environment and resources |
| **CONCLUSION** |
| Reduced anthropogenic pressures on the environment, however the risk remains that increased and irresponsible resource use and environmental degradation may occur to fuel the economic growth |

### Impacts on ecosystem functioning

The Rabbit scenario is characterized by a structured stable society and a diversified economy with access to finance and capital for investment. Good governance restricts cropping to Capability Classes I to IV and access to resources enable communities to maximize food production in these areas. The majority of households reduce their herd sizes in order to improve livestock condition however the persistence of poverty levels still encourage some poor household to maximize herd sizes. Good governance results in grazing management plans being implemented and enforced thereby resulting in improved rangeland condition. Some degraded areas are also rehabilitated resulting in an overall improvement in the condition of grasslands and wetlands.

While there is likely to be a slight reduction in the supply of provisioning, regulating and supporting services as cultivation expands, the restriction of this transformation to Classes I to IV enables the conservation / sustainable management of large tracts of natural areas. As a result, the supply of provisioning, regulating and supporting services stabilize at a reasonable level.

Food production is likely to increase significantly when compared to baseline conditions. This impact is as a result of an increase in the area under cultivation coupled with improved inputs and management of existing croplands. Figures 5.2.1, 5.2.2, and 5.2.3 also illustrate a slight reduction in grazing, thatching and fuel resources however these services will be available all year round. In addition, good governance structures ensure equitable access to these resources by all households.

Importantly, there is likely to be a reasonable supply of all regulating and supporting services. The levels of these may increase further from those displayed in Figures 5.2.1, 5.2.2 and 5.3.3 with an improvement in their condition as a result of effective rangeland management and rehabilitation. The overall supply of provisioning and regulating and supporting services is highest under this scenario as illustrated by the high scores displayed in Appendix E (Figures E4, E5, and E6).

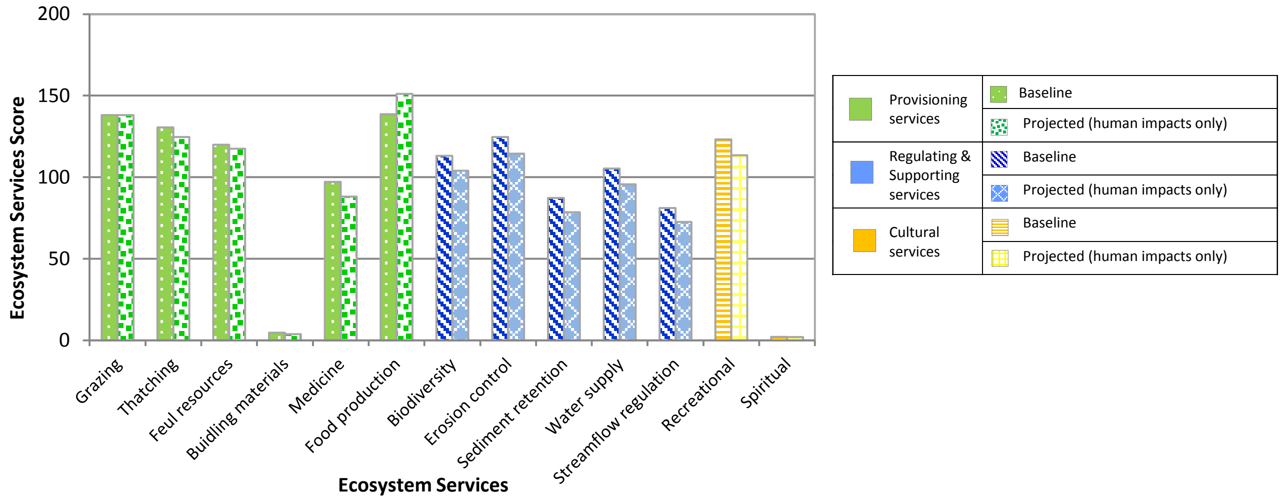



**Figure 5.2.1:** Projected change in ecosystem services at Setibi under the Rabbit Scenario

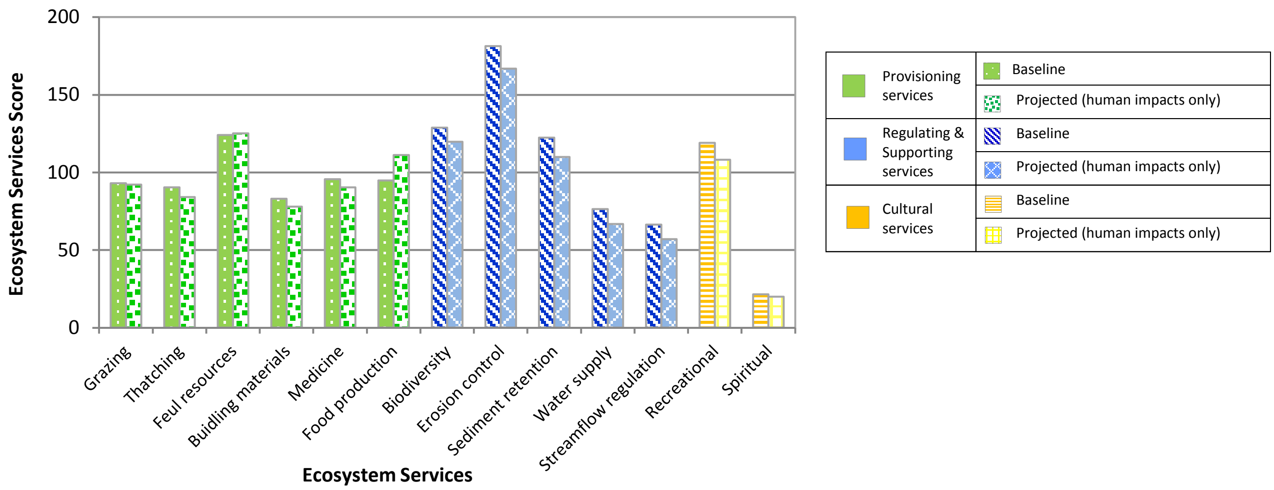



**Figure 5.2.2:** Projected change in ecosystem services at Muela under the Rabbit Scenario

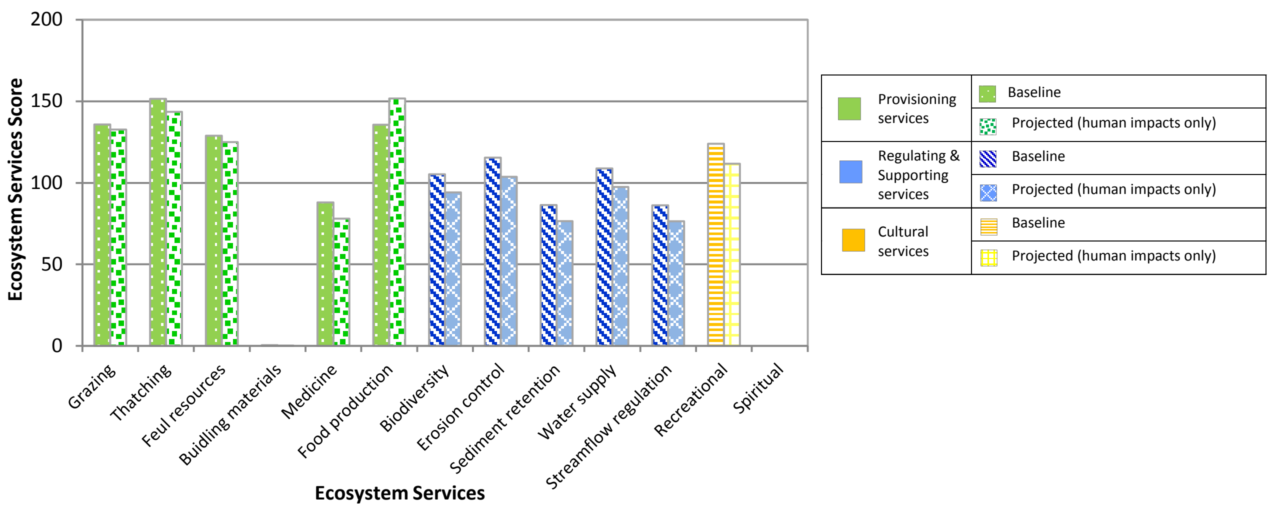



**Figure 5.2.3:** Projected change in ecosystem services at Sepinare under the Rabbit Scenario

## Impacts on agriculture

Agricultural production in this scenario becomes more efficient and starts to take on a more commercial focus, although not at the expense of food security. All households have access to enough croplands to meet their food requirements, although this this is attributed largely to higher output per unit area than to increased land under production.

A range of 'climate smart' cropping systems and technologies are introduced as Lesotho cooperates at a national level with neighbouring countries to share technologies and experiences. This results in an integrated climate smart policy, addressing social, economic and environmental aspects of climate change. Policies are effectively translated into actions on the ground through effective extension services that work closely with village and district leadership to introduce new agricultural technologies.

The yields and the diversity of crops being produced are greatly enhanced as a result of this and improved cultivation techniques, such as intercropping, zero tillage and agro-forestry are introduced. Plant breeders work with local communities to develop seed varieties that are well adapted to the short growing season. Soil conservation systems are enhanced and contours and waterways are developed into an integrated system, further limiting erosion. New technologies enhance soil fertility and organic matter without the need for external inputs. Infiltration is enhanced and soil water holding capacity is improved. Crop outputs per unit rainfall are increased. Farmers are producing a surplus in good years, which they sell or trade for other goods. Farmers are actively seeking new lands to grow crops as they have cash to invest in production.

Livestock production is improved as more control over stocking rates is exerted. Livestock owners are assisted in finding ways of optimising production through regular off-take of excess animals and genetic improvement of livestock. With lower pressure on the rangelands, fodder quality and production gradually improves, further enhancing livestock quality. With improved genetic stock and nutritious grazing, the quality of livestock products, particularly wool, are much improved, which means a create cash income for livestock owners even though herd and flock sizes are reduced.

**Livelihood trajectories and trade-offs**

Local economic development is achieved and poverty levels are reduced, but this is not driven through short term maximization of provisioning services. Capital and technology allows for economic development and livelihood diversification associated with a range of value adding initiatives. These include improved farming systems (generating higher yields without expanding fields or herd sizes) local processing and beneficiation initiatives stimulating and growing markets for trade locally and with areas outside of the Highlands. The slight reduction in grazing and opportunities for harvesting of certain natural resources is off-set with increased cash incomes which are used to purchase alternatives. The vulnerability of households is therefore not negatively affected and the overall resilience of livelihoods is improved.

The structured and stable society means that there is an equitable distribution of benefits from development opportunities, resulting in coordinated and collaborative efforts to sustainably manage and even rehabilitate the environment. Less pressure on provisioning services from the environment means that no tradeoffs are made in ecosystem services which sustains ecosystem functioning and benefits from regulating and supporting services are maintained. Planning horizons are extended and efforts are made to improved environmental management as the benefits and returns from improved ecosystem functioning in the long term are recognized and invested in. Examples of investment include wetland conservation and soil conservation result in improved water flow regulation etc.

## 5.3 Vulture Scenario

**Summary of key scenario attributes**

| |
|---|
| **POSITIVE** |
| Diversified economy – some economic development resulting from access to finance and capital by minority. |
| Some local level value adding – but limited to entrepreneurial minority. |
| Minority '*Haves'* able to invest in infrastructure and services to meet own needs. |
| **NEGATIVE** |
| Diversified economy - disparities in access to finance –limited economic diversification and development. |
| Unstructured and unstable society - disparities between opportunistic/entrepreneurial minority ('*haves'*) and un-capacitated majority ('*have-nots'*). |
| No social cohesion - each household looking only after its own interests. |
| On-going unabated poverty levels - drives resource use and environmental pressure. |
| Mixed livestock operations - few large, well maintained, commercially oriented, herds owned by '*haves'* and large number of small subsistence herds owned by '*have-nots'*. |
| No control of livestock grazing and numbers – '*haves'* manipulate grazing management plans which undermines long term sustainability of the rangelands. |
| Lack of capacity and capital locks '*have-nots'* into primary and subsistence level crop production. |
| Insecure land tenure - '*haves'* use influence to secure land at expense of '*have-not'* households. |
| Lack of effective governance and planning - unscrupulous/irresponsible expansion of cultivation and unsustainable resource harvesting. |

| |
|---|
| Settlements expand across the landscape - economic disparities result in variation in levels of infrastructure and services - escalates environmental and pollution pressures. |
| **CONCLUSION**<br>Maximisation of short term resource use by all households to meet their own self-interests takes place the expense of long-term sustainability.<br>Despite widespread environmental degradation - no rehabilitation or conservation initiatives at all. |

## Impacts on ecosystem functioning

The Vulture scenario is defined by disparities in access to finance with the '*have-nots'* exposed to high levels of poverty while the '*haves'* are wealthy and able to exploit resources to further their wealth. This scenario results in the cultivation of Classes I, II, III, IV, V, VI and VII with the "haves" concentrated in the higher production areas and the '*have-nots'*" forced to cultivate marginal areas to survive. Livestock numbers are likely to increase as the "haves" increase their herd sizes. These animals are able to graze at will as grazing management plans are not implemented or enforced. These pressures result in a significant decline in the condition of the ecosystems and extensive loss of grasslands, shrublands and wetlands.

The '*haves'* are able to access capital and finance and are thus able to maximize food production in the high production areas. However food production by the '*have-nots'* in the marginal areas is likely to decline significantly, which forces them to abandon lands and try again in other marginal areas. Thus the increase in food production illustrated in Figures 5.3.1, 5.3.2 and 5.3.3 is unlikely to be as high as shown given the poor condition of the cultivated areas by the '*have-nots'* although it will be higher than baseline conditions given the extensive increase in cultivation and the inputs and management of high production areas by the '*haves'.*

Only slight declines in grazing, thatching and fuel resources are anticipated. This is because the loss of grasslands may reduce the availability of grazing however this will be tempered by an increase in fodder available from cultivated areas. It is important to note that this shift in supply of this service will be seasonal with stover only available during the winter months compared to grasslands which were available year round. This is likely to place greater pressure on the alpine areas as animals will have to remain in these areas for the majority of the year, returning only for short periods over winter. In addition, the conversion of shrublands to croplands will reduce the browse availability for goats.

Similarly, some fuel resources such as *Buddleja* and *Leucosidea* will be lost through the transformation of natural areas to croplands however the supply of *Artemesia*, which thrives in old lands, is likely to increase thereby providing an alternative fuel resource. As with the grazing, the supply of fuel resources will be limited to winter when the crops have been harvested allowing *Artemesia* to grow however should there be a cold snap during the growing season, there will be limited or no fuel resources available. Extensive areas of ploughed lands are also likely to be separated by *Hyparrenhia* and thus thatching materials could increase. These changes in thatching and fuel resources are likely to be greatest on land owned by the '*haves'* and thus access to these resources by the '*have-nots'* may be limited.

This transformation of natural areas results in a corresponding loss in all regulating and supporting services (Figures 5.3.1, 5.3.2 and 5.3.3). The reduction in grasslands, particularly the *Themeda-Festuca* grasslands at Sepinare and Setibi is likely to result in increased run-off and erosion and a decline in the water supply function of the environment. Biodiversity is also anticipated to decline dramatically and the loss of wetlands to agriculture will significantly reduce streamflow regulation.

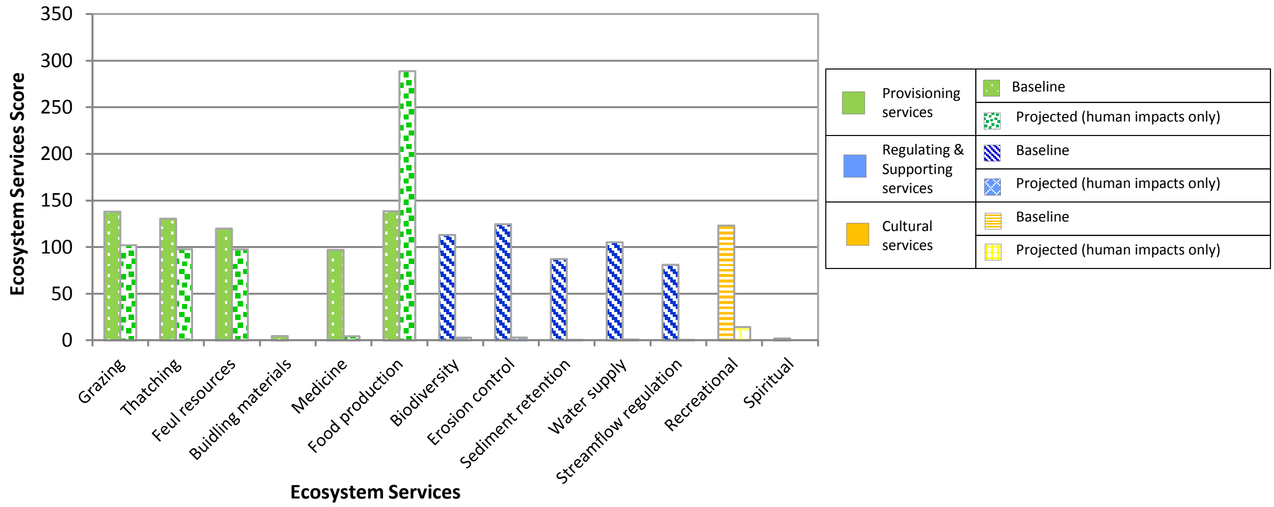



**Figure 5.3.1:** Projected change in ecosystem services at Setibi under the Vulture Scenario

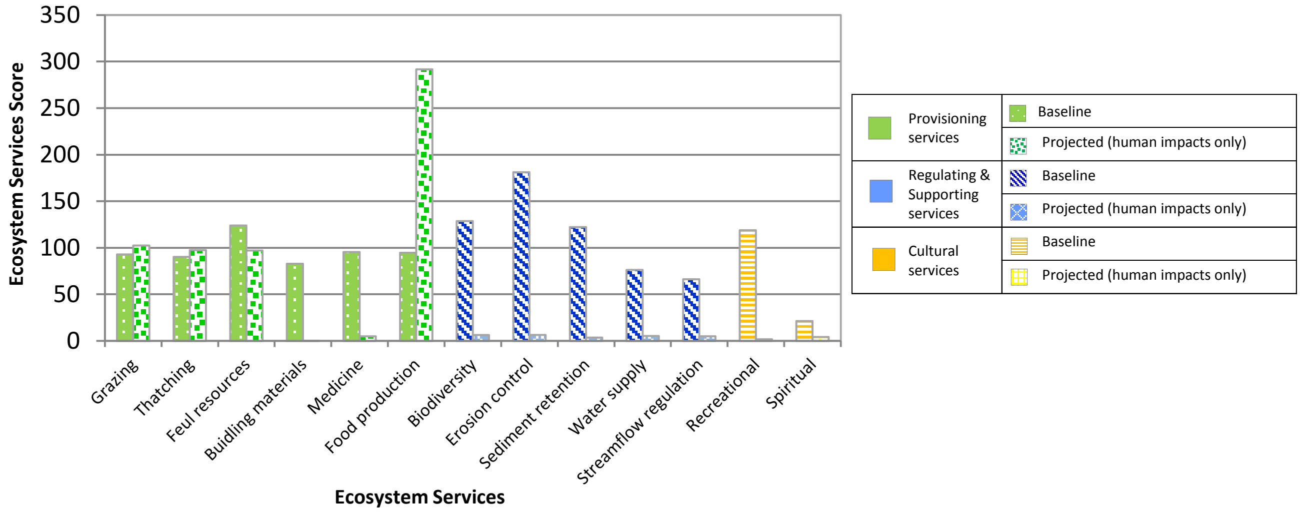



**Figure 5.3.2:** Projected change in ecosystem services at Muela under the Vulture Scenario

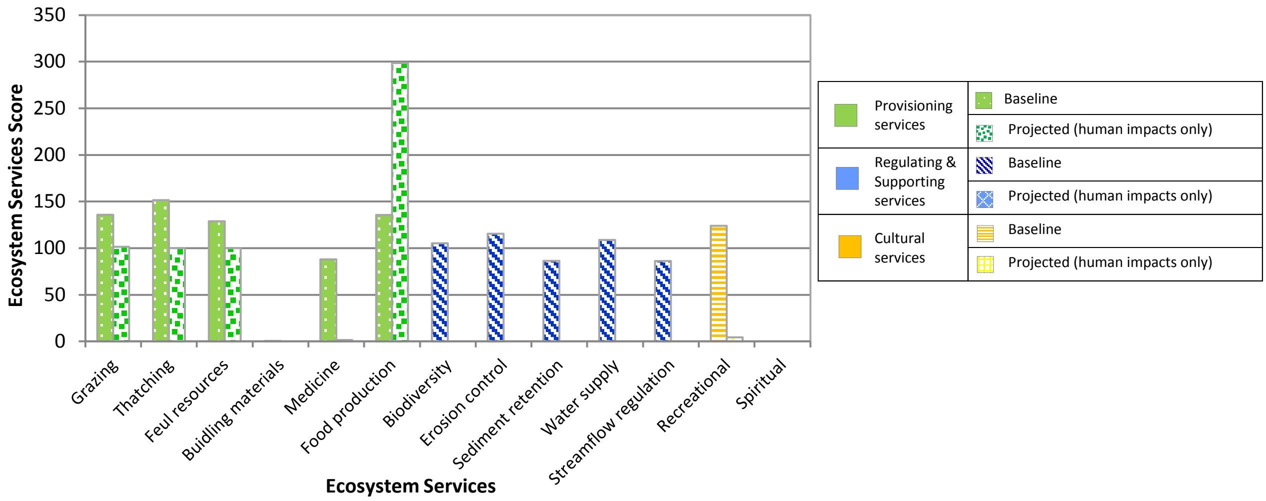



**Figure 5.3.3**: Projected change in ecosystem services at Sepinare under the Vulture Scenario

The impacts on ecosystem services as a result of the transformation of Capability Classes I to VII are likely to be greatest at Sepinare and Setibi as small tracts of land which provide some services are still present in Capability Class VIII at Muela (Appendix E, Figures E8 and E9). However the reduction in condition will reduce the ability of the ecosystem to provide provisioning, regulating and supporting services and thus the ecosystem services scores for all three sites under this scenario are very low (Appendix E, Figures E7, E8 and E9).

## Impacts on agriculture

Agriculture in this scenario is characterised by increases in production due to expansion in field areas, which occurs at the expense of the natural resource base. Subsistence agriculture is practiced by most of the population, but there are a few who are more commercially focussed and aim to maximise production in the short term for their own gains.

A dichotomy in crop production begins to emerge as a few commercially oriented farmers (the '*haves*') with resources improve their production systems by investing in improved seed varieties and some fertilisers. Subsistence farmers (the '*have-nots'* who make up the majority) remain producing at low levels and often do not have sufficient food to meet their needs for the year. The 'commercial' farmers invest in value adding activities, such as milling grains and charge subsistence farmers for this service and their income sources diversify as a result. In some cases, subsistence farmers cannot afford to plough their lands and end up forfeiting their land due to the imbalanced power dynamics that exist in the community.

Livestock ownership is characterised by a few individuals (the '*haves'*) with large, reasonably well maintained herds and flocks. Genetic stock has been improved to make the most of the meager and dwindling rangeland resources. Conflict between the commercial and subsistence livestock owners (the '*have-nots'*) over grazing land and allocation starts to emerge and commercial owners increasingly seek more grazing land. Subsistence livestock owners are increasing marginalised and their access to grazing land is reduced with the result that mortality increases.

## Livelihood trajectories and trade-offs

Increasing disparities between the 'haves' and '*have-nots*' contributes to a breakdown of social cohesion and drives the development of an '*each man for himself'* approach to livelihoods. The entrepreneurial and relatively empowered minority uses their position to leverage increasing benefits and opportunities, frequently at the expense of the disadvantaged majority. Power of the '*haves'* is used to take advantage of weak and ineffective policy and governance systems. Ultimately, which the '*haves'* are able to alleviate poverty within their own families, the majority of households' livelihood resilience is eroded and they become increasingly vulnerable. Lack of social structure and stability also results in weak tenure rights and the disadvantaged households increasingly lose their land rights to the '*haves'* who demonstrate that they can use it more effectively and supposedly for the benefit of the community in general. In many cases, subsistence farmers and livestock owners end up seeking employment as cheap labour from the 'haves', and become increasingly marginalized. Their priority is therefore to maximize short term benefits from the environment which results in unsustainable resource harvesting and expansion of crop production into completely unsuitable and marginal crop production areas. The '*haves'* drive to maximize the returns using their relatively powerful positions also drives them to maximize short term resource use and farming opportunities. The long term ecosystem functioning, and the generation of regulating and supporting services, are traded-off against maximization of short term benefits from provisioning services by the '*haves'* and '*have-nots'*. This undermines the ability of the environment to support and sustain the agricultural and resource use activities of both the '*haves'* and the '*have-nots*' with a gradual decline in benefits for both. Even the '*haves'* ability to invest in production activities (for example with fertilizers and improved technology) cannot compensate for the decline in ecosystem services. Livelihood resilience of local households is therefore increasingly compromised (for '*haves'* and '*have-nots'*) with increasing risk of extreme events and shocks resulting in complete crop failure and livestock losses.

The deterioration of long term ecosystem functioning, and the degradation of regulating and supporting services such as streamflow regulation, water retention and habitat provision will result in downstream problems such as flash floods, increasing soil erosion and sediment loads entering rivers and dams, drying up of springs and wetlands etc. This will ultimately have dire consequences for households living in these areas, as well as for downstream (in the lowlands of Lesotho as well as South Africa), who also benefit and rely on the ecosystem services generated in the Highlands.

## 5.4 Jackal Scenario

### Summary of key scenario attributes

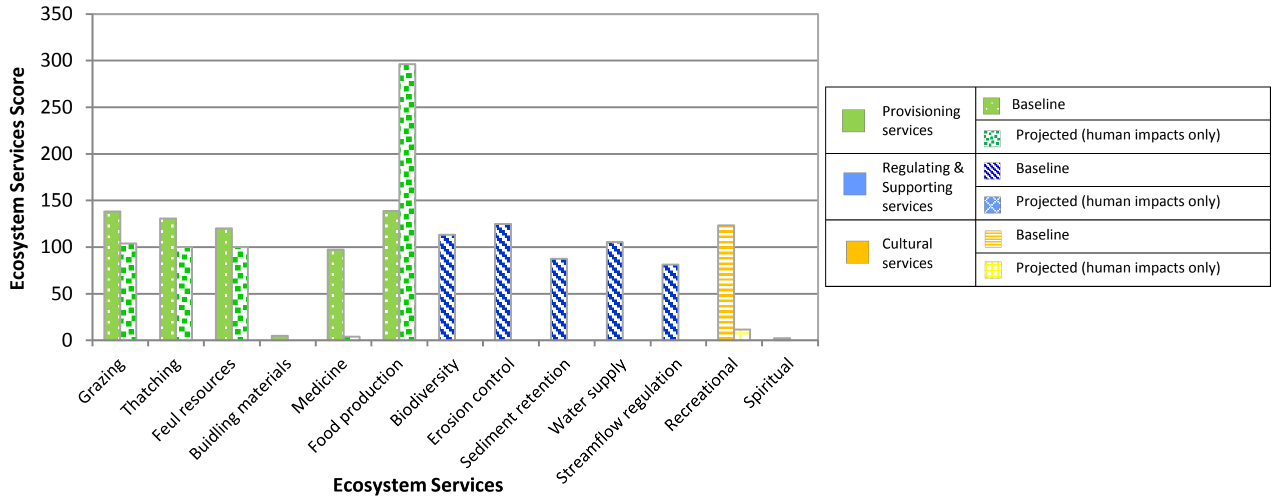
| |
|---|
| **POSITIVE** |
| Population growth rate negative – no population growth - no increase in environmental or resource use pressure typically associated with growing population pressures |
| No settlement expansion – no increase in environmental impacts associated with expanding settlements or economic growth |
| **NEGATIVE** |
| Unstable/unstructured society - no social cohesion - absence of effective governance and policy. |
| No planning or investment in critical infrastructure and services such as health care and education. |
| Population growth rate quickly becomes negative due to increasing poverty and lack of health care - skewed age distribution - land and resources in control of elderly - unable to utilise to its full capacity. |
| Declining health care and welfare support - increasing incidence of OVC - high vulnerability and dependency levels in the Highlands. |
| Single sector undiversified local economy - largely subsistence level agricultural systems - no access to capital for investment - lack of economic growth in Highlands. |
| Absence of effective governance systems - no management of resource use - classical 'tragedy of the commons' and environmental degradation. |
| Declining production in all agricultural systems - large livestock herds in very poor condition, vulnerable to disease and high mortality rates. |
| Uncontrolled/indiscriminate grazing of summer cattle posts and lower altitude winter rangelands - exacerbates rangeland degradation and loss of important habitats such as wetlands. |
| Crop production focused on a single staple crop (maize) - lack of technology, skills or resources to invest - declining crop yields - pressures to expand field sizes in effort to maintain overall production levels. |
| Uncontrolled expansion of cropping areas - escalating environmental degradation. |
| Environmental degradation such as soil erosion - no efforts or resources available for rehabilitation. |
| No local value adding - households consume whatever they are able to produce - no local market or trade. |
| Lack of or declining levels of services and infrastructure in settlements - intensifying environmental degradation. |
| **CONCLUSION** |
| Unscrupulous use of natural resources - everyone only concerned by meeting their own needs and maximising whatever benefits they are able to for themselves. |
| Uncontrolled self-serving use of natural capital to meet short term needs in attempt to alleviate poverty. |

### Impacts on ecosystem functioning

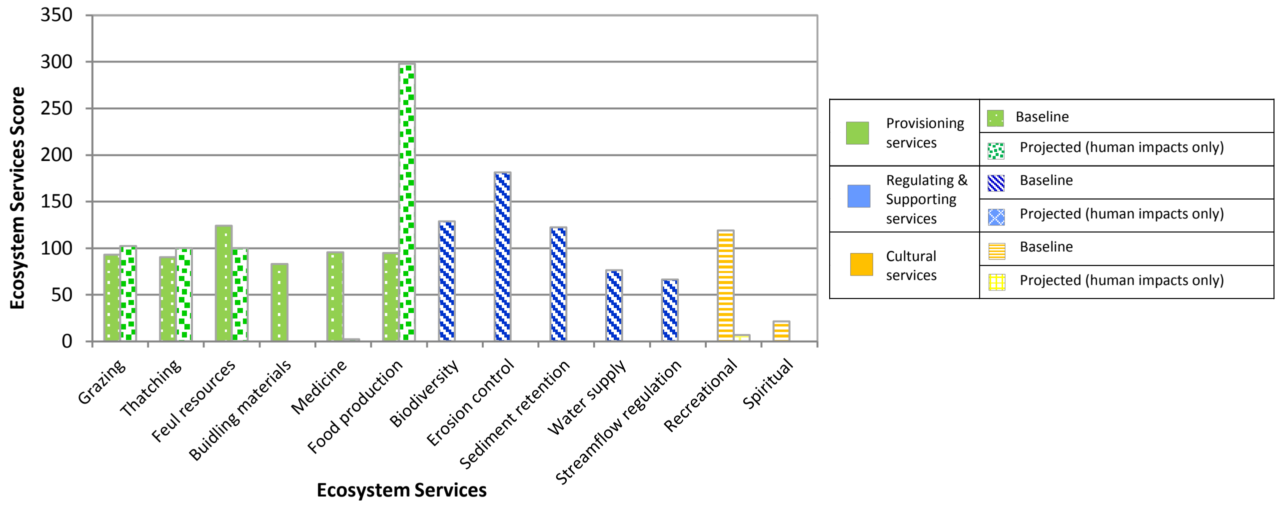
The lack of economic opportunities, social cohesion and governance under the Jackal scenario increases the reliance of households on agriculture and natural resources. As a result, all available land is cultivated (Capability classes I to VIII) in an attempt to meet food security needs. Although Figures 5.4.1, 5.4.2 and 5.4.3 illustrate the significant increase in areas under food production, the reality is that poor management (i.e. lack of skills and technology) and a lack of inputs (i.e. access to capital and finance) is likely to result in a decline in food production compared to baseline levels.

While other provisioning services such as grazing, thatching and fuel resources show a slight decline or a marginal increase, the supply of these services will be seasonal as a result of cropping patterns (Figures 5.4.1, 5.4.2 and 5.4.3). Thus, fodder from cultivated areas will only be available during the winter months compared to the year round supply of grazing when these areas were under grasslands. In addition, the only fuel resource available is likely to be *Artemesia* which will only be available in fallow lands. Thus while these areas are under crops, there is likely to be a significant shortage of resources available for fuel. Building materials and the availability of plants for medicinal purposes will decline dramatically under this scenario (Figures 5.4.1, 5.4.2 and 5.4.3).

Most importantly, the ability of the environment to supply critical regulating and supporting services will be severely compromised. The conversion of wetlands, grasslands and shrublands to agriculture coupled with inappropriate management of the transformed areas will result in biodiversity loss, increased soil erosion and reductions in streamflow regulation and water supply. This may ultimately lead to ecosystem collapse with dire consequences for households living in these areas. These impacts are likely to be equally catastrophic across all three sites (Appendix E, Figures E10, E11 and E12).




**<u>Figure 5.4.1:</u>** Projected change in ecosystem services at Setibi under the Jackal Scenario




**<u>Figure 5.4.2:</u>** Projected change in ecosystem services at Muela under the Jackal Scenario

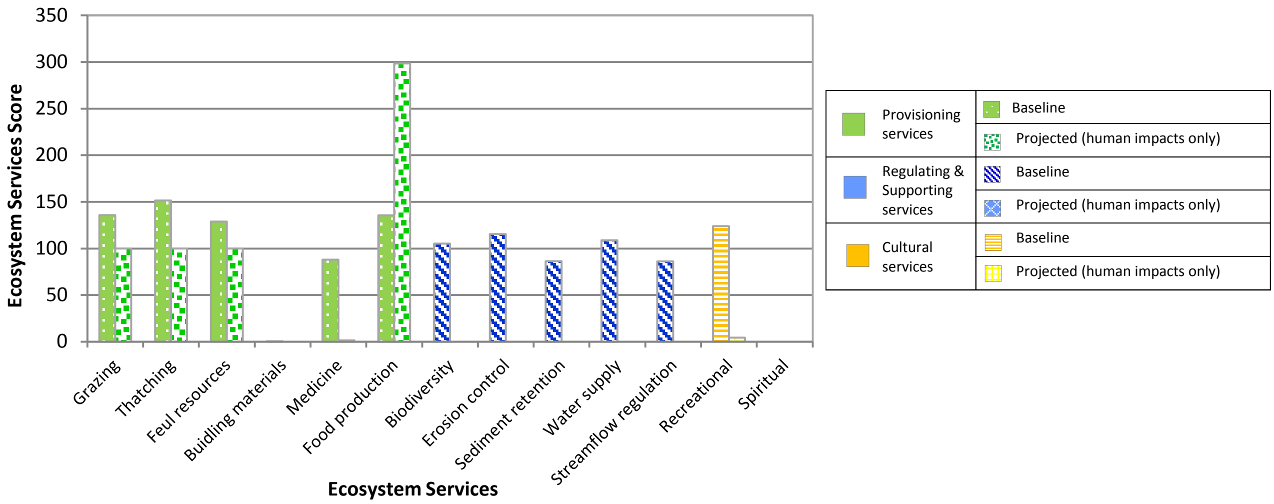



**Figure 5.4.3**: Projected change in ecosystem services at Sepinare under the Jackal Scenario

## Impacts on agriculture

Undiversified subsistence agriculture remains the dominant form of production in this scenario. All farmers are equally impoverished and the provision of services and infrastructure is declining. Governance is ineffective as there is not guiding policy or structures to map a path going forward.

Crop production focuses only on maize. Production deteriorates as soil conservation structures crumble and the mining of soil nutrients can no longer support the levels of production necessary to meet food security needs. Farmers are forced to cultivate increasingly marginal lands to meet their food requirements. Loss of topsoil due to water erosion is common and large gulleys develop in waterways near crop lands. Fertile sediments are washed into streams and rivers.

The encroachment of cropping lands into what was traditionally grazing land places further pressure on livestock, particularly during the lean months just before the onset of the summer rains. Cattle and oxen are hardest hit, as their feed requirements are higher than that of small livestock. This limits the availability of animal traction and many farmers have to prepare their land by hand. All households seek to maximise the number of animals they have grazing the rangelands, resulting in a typical tragedy of the commons scenario.

## Livelihood trajectories and trade-offs

Despite the efforts of households, returns from crop production and livestock are increasingly meager, and households are exposed to higher levels of hardship with food shortages and ill-health becoming dominant characteristics in the Highlands. There is no local livelihood or economic diversification and households rely on primary production and the provisioning services of the environment. The resilience of livelihoods is low, and households are very vulnerable to shocks and extreme events.

Households' and communities' financial and social capital is eroded. There is increasing out-migration from the area with individuals and even entire families relocating in an attempt to find a more secure livelihood. Those remaining increasingly maximize land use opportunities (cultivation, grazing and resource harvesting) even though it is at the expense of the environment, as there are no alternatives available to them for meeting livelihood needs. Lack of resources, capacity and social cohesion means that there are no efforts to manage or mitigate the negative impacts to the environment and there is no rehabilitation of degraded areas.

The maximisation of short term provisioning benefits from the environment is traded off against long term ecosystem functioning, and the generation of equally important regulating and supporting services. The ability of the environment to supply critical regulating and supporting services will be severely compromised, which in turn undermines the ecosystems ability to continue to supply provisioning services. Productivity and yields from agriculture will decrease (provisioning services) as a result of a breakdown in nutrient cycling, soul formation and water retention processes (regulating and supporting services). In addition, streamflow regulation, water retention and habitat provision will deteriorate resulting in downstream problems such as flash floods, increasing soil erosion and sediment loads entering rivers and dams, drying up of springs and wetlands etc. This will ultimately have dire consequences for households living in these areas, as well as for downstream (in the lowlands of Lesotho as well as South Africa), who also benefit and rely on the ecosystem services generated in the Highlands.

# 6 COMBINED IMPACTS OF CLIMATE CHANGE AND SCENARIOS

## 6.1 Tortoise Scenario

### Impacts on ecosystem functioning

#### *6.1.1.1 Impacts on ecosystem functioning*

The Tortoise scenario displays few changes in provisioning services but dramatic reductions in regulating and supporting services. Anthropogenic impacts, rather than climate change, are the major driver of these changes (Figures 6.1.1 and 6.1.2).

Under this scenario, increasing temperatures and precipitation are likely to result in increases in food production beyond those illustrated for this scenario without the impacts of climate change. However, the risk of crop failure as a result of extreme events and intermittent rainfall is likely to be high necessitating the need to cultivate Capability Classes I to VI. This need is further compounded by the lack of economic opportunities under this scenario.

An increase in atmospheric $CO_2$ concentrations is likely to increase the extent of shrublands, trees and streambank vegetation (particularly *Salix* sp). This will have significant benefits for households as it will temper the loss of fuel resources as a result of conversion of shrublands to croplands (in Capability Classes I to VI). The increase in shrublands as a result of climate change will also assist in ensuring a year round supply of fuel resources. Under this scenario, without climate change, *Artemesia* is likely to be one of few remaining fuel resources. However the availability of this resource would depend on the availability of uncultivated lands and would therefore be a seasonal occurrence. Thus the increase in shrublands as a result of climate change will temper this seasonal availability of fuel resources and help to buffer communities against extreme events.

The increase in shrublands does however come at the expense of many of the grassland communities, particularly *Aristida*, *Harpochloa* and *Themeda.* However the movement of C3 temperate grasses down the slopes may increase the grazing capacity of some areas although these changes are likely to be negligible. Overall, the loss of many of the grasslands to shrublands coupled with overgrazing and poor management is likely to result in a reduction in both forage quantity and quality. Furthermore, the conversion of large areas to cultivation may on occasion increase the availability of winter fodder however the increase in crop failure also heightens the risk of losing this important forage material.

The increased clearing of land for cropping will exacerbate the projected loss of wetland functionality. However, limited governance may restrict some cultivation of these areas thereby reducing this impact. The general increase in croplands and their limited management coupled with the projected increase of more intensive rainfall events will likely result in some sediment deposition within low-lying wetlands and water bodies. A decline in water quality entering water bodies within the catchments is likely to occur. This will adversely affect the important regulating and supporting services, such as streamflow regulation, that these areas provide.

All regulating and supporting services are still expected to decline although shifts in some vegetation communities as a result of climate change may improve the situation slightly Figures 6.1.1 and 6.1.2[8]). However as with grazing, this improvement is likely to be negated by poor sustainable land management.

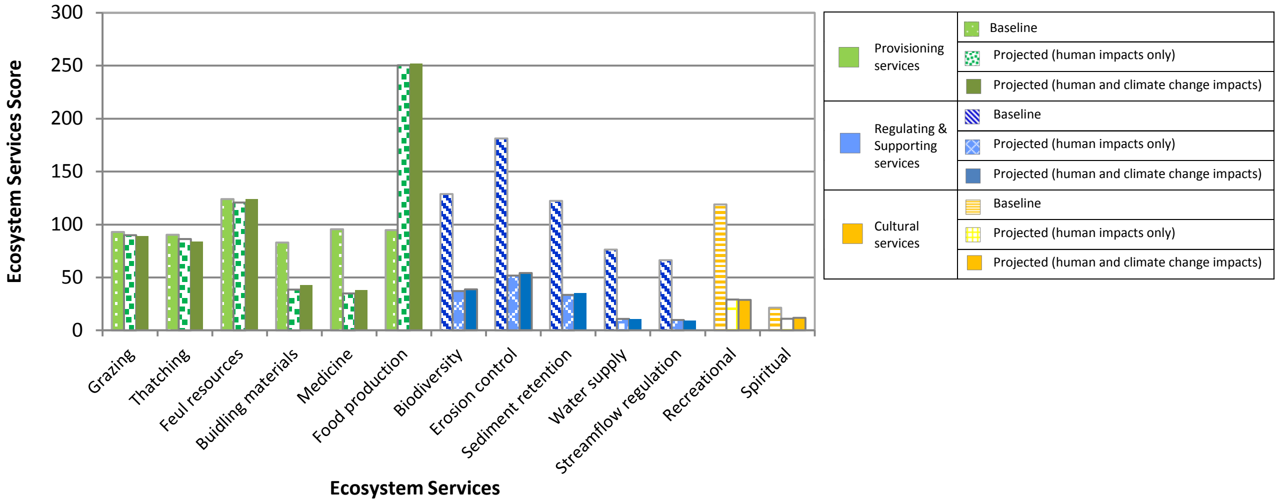



**Figure 6.1.1:** Projected change in ecosystem services at Muela under the Tortoise Scenario as a result of anthropogenic factors and climate change

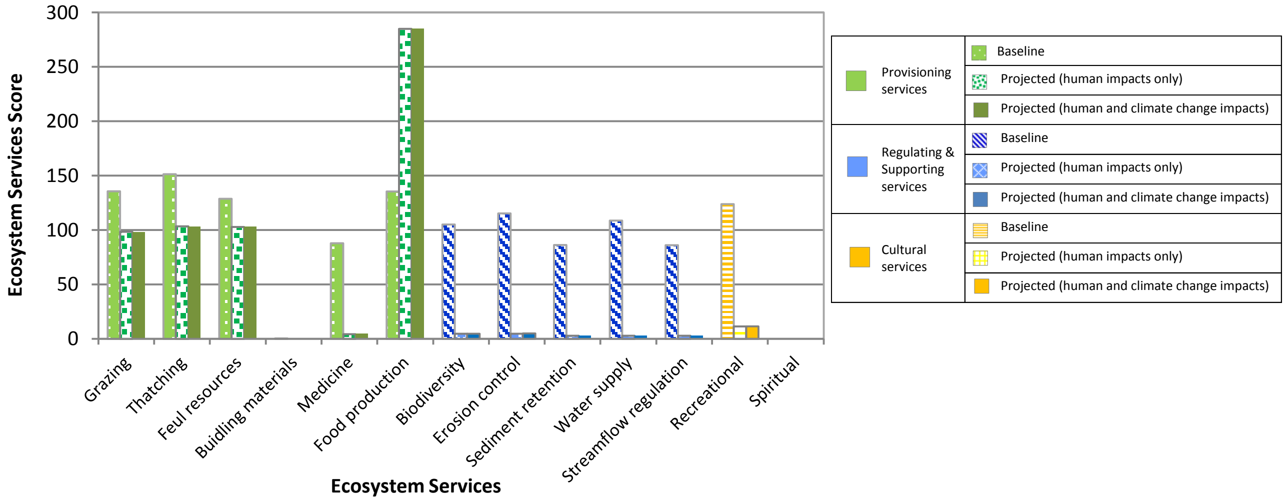



**Figure 6.1.2:** Projected change in ecosystem services at Sepinare under the Tortoise Scenario as a result of anthropogenic factors and climate change

## Impacts on agriculture

Good governance and social cohesion mean that soil conservation structures and management techniques are reasonably well applied, although new and improved agricultural technologies remain poorly developed.

8 Analyses of Setibi for all scenarios are currently being revised and will be included in the next version of this report.

With increased rainfall and more frequent heavy rainfall events, erosion is limited due to the presence of conservation measures and soil moisture retention is generally improved. Improved soil moisture conditions, combined with increased temperatures mean that crop yields are slightly higher. However, the full benefits of these favourable production factors are not realised because improved cropping systems and techniques have not been developed. Crop diversity remains low and frost and drought tolerant species and plant varieties are not planted. This makes farmers vulnerable to unseasonable climate extremes, such as late and early frosts and dry spells in the summer months. There is an increase in the incidence crop pests and diseases, particularly in the warmer and wetter month. This sets back some of the gains in yield achieved due to increased temperature and rainfall.

With continued overstocking of the rangelands, grass cover remains poor, even though net primary productivity is increased. Less palatable species continue to dominate and basal cover deteriorates. As a result, animal condition and vigour continues to deteriorate, especially in the late winter and early summer periods before the onset of the first rains. The higher temperatures in particular result in greater parasite infestations and a higher incidence of tick borne disease.

The net effect in this scenario is a slow steady decline in both animal and crop production, which reduces food security and increases vulnerability to climate change and variability.

## Livelihood trajectories and trade-offs

While household livelihoods initially remain relatively stable, the increased seasonality of access to certain resources and agricultural production, associated with the impacts of climate change, begin to erode into the resilience of livelihoods. While households are able to initially cope with shocks and crop failures associated with extreme climatic events (e.g. floods, droughts, heavy snow, etc.) the increasing frequency of these incidence makes it more and more difficult for households to recover from each event and the resilience and coping capacity of households’ declines. This together with the slow steady decline in both animal and crop production decreases households’ ability to sustain themselves and they become increasingly dependent of welfare social support and aid programmes.

As poverty levels increase, land and resource use increasingly becomes focused on meeting short term needs and therefore on maximizing provisioning services. Medium to long term planning time horizons and environmental conservation and rehabilitation efforts are seen as an unaffordable luxury. This however ultimately further undermines the ecosystems’ provisioning capacity by eroding the regulating and supporting services. Environmental consequences such as landslides, soil erosion and declining soil fertility exacerbate the threats and risks to the sustainability of the livelihoods of the resource dependent communities in the Highlands.

The strong social networks and cohesion within communities, and the effective governance systems means that households support each other as best they can particularly the most vulnerable, orphans and children. However because the resilience of all households is eroded over time they become less able to provide support to others. Lack of skills, capacity and access to finance limits the ability of households to break the negative spiral themselves. Poverty levels gradually increase and outside support (e.g. national and donor programmes) become a necessity to avoid disasters such as famine and malnutrition associated with widespread crop failures.

## 6.2 Rabbit Scenario

### Impacts on ecosystem functioning

The Rabbit Scenario is characterized by good governance and access to resources which result in improved management of natural resources. This management coupled with some benefits of climate change result in only a marginal decrease in many of the services compared with current conditions (Figures 6.2.1 and 6.2.2).

While only Capability Classes I to IV are cultivated, access to resources enables production on these areas to be maximized. Increases in temperature and precipitation therefore contribute to even higher yields being produced on these lands compared to this scenario without climate change impacts. However crop failure is still high but alternative economic activities create a buffer to this risk for households.

The shift in some grassland communities to shrublands (as a result of climate change) provide a range of benefits including increases in building materials, medicine and fuel resources. Governance structures under this scenario also facilitate equitable access to these resources. In addition the benefits from the increase in fuel resources is realized under this scenario as not all areas are cultivated. Although this shift has come at the expense of the grasslands, better management and reduced livestock numbers result in an overall improvement in rangeland condition. Furthermore, the migration of C3 temperate grasses down the slope (as a result of climate change) increase the condition of available grazing as they remain greener for longer periods of time. These areas are also carefully managed under this scenario and thus the benefits of this improved grazing persist.

While anthropogenic activities still contribute to a decline in regulating and supporting this is buffered slightly by projected changes as a result of climate change. The increase in alpine areas coupled with good management results in the persistence of a similar number of species to that under the current situation however changing climatic conditions may still result in the loss of some rare and endemic species. In addition, the increase in alpine areas in a good condition improves water supply and reduces sedimentation while the increase in shrublands assists with erosion control.

Wetlands are likely to retain their functionality as good governance structures and access to resources will prevent poor land management practice, i.e. prevent the cultivation of wetlands and aid in facilitating with the rehabilitation of degraded areas, thereby retaining or enhancing important regulating and supporting services. Overall most ecosystem services will persist at a reasonable level.

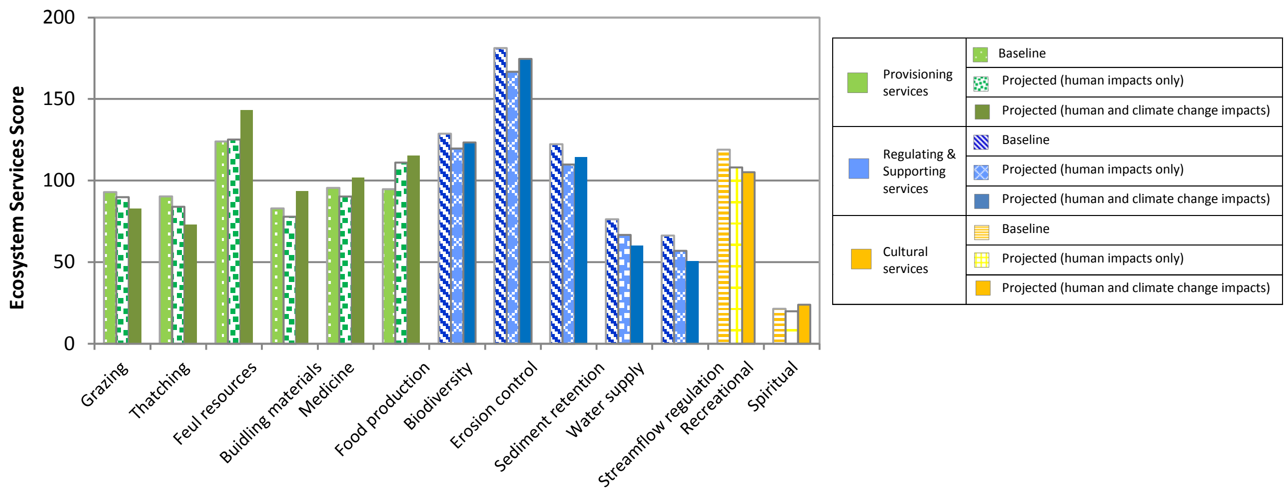



**Figure 6.2.1:** Projected change in ecosystem services at Muela under the Rabbit Scenario as a result of anthropogenic factors and climate change

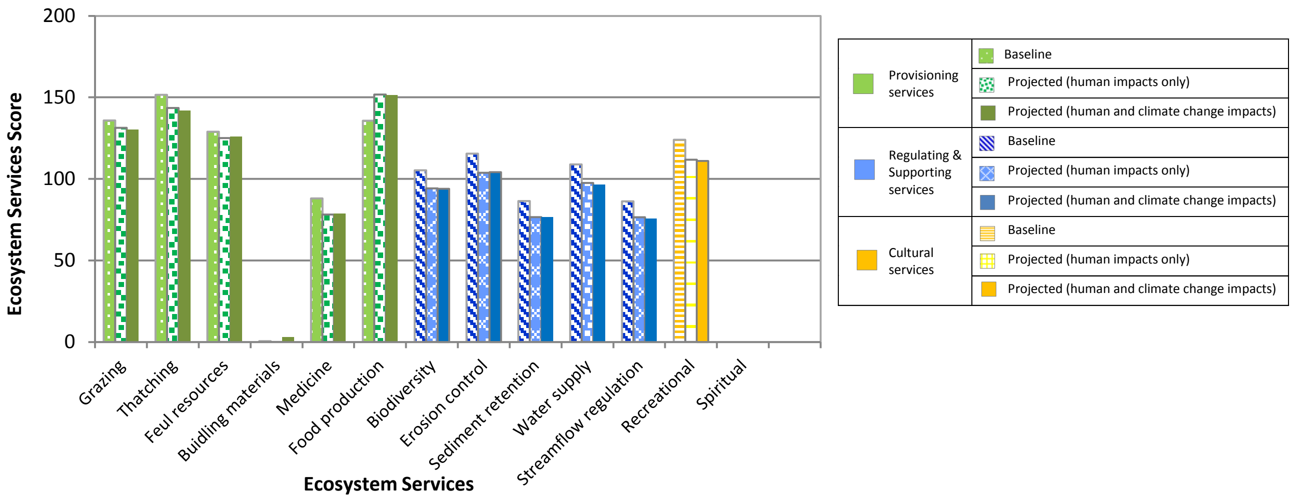



**Figure 6.2.2:** Projected change in ecosystem services at Sepinare under the Rabbit Scenario as a result of anthropogenic factors and climate change

## Impacts on agriculture

In this scenario, with a structured and stable society and a diversified economy, a range of new technologies and production systems are introduced under the banner of 'climate smart' agriculture.

New techniques such as conservation agriculture, intercropping, zero tillage and agroforestry result in significantly enhanced crop diversity, improved soil structure, condition and fertility and improved soil water holding capacity. In dry years, crop production is slightly higher than current levels of production. In wetter years, significant crop surpluses are produced. The diversity of varieties and different crops planted mean that extreme events have a limited impact on overall production, which significantly reduces climate risks. Furthermore, the conservation agriculture techniques maintain and enhance soil depth and reduce soil loss due to water erosion. While disease risk is elevated due to higher temperature and higher humidity, these risks are mitigated by the diversity of crops being produced, intercropping, companions planting and the use of natural and traditional pest control measures.

Due to improved control and management of livestock stocking rates, there is an increase in plant basal cover and an increase in the number of more palatable species. Increased basal cover significantly reduces the exposure of soils to erosion and gradually increases soil organic matter content, which further increases sol resilience and fertility. The improved cover and palatability mean increased animal production and performance. While the composition of the rangeland species changes, overall productivity of the rangeland increased due to improved rangeland management practices. The impact of higher incidences of disease is mitigated by improved animal vigour and the effective use of control measures (vaccines, dips, etc.) implemented with the assistance of state extension services.

The net effect under this scenario is an overall increase in crop and animal production and stable, food secure communities who have a high resilience to climate change and climate variability.

## Livelihood trajectories and trade-offs

The diversification of livelihood strategies provides a buffer for households against the increased seasonality and extreme events associated with the impacts of climate change. Diversification of agricultural production means that if some crops fail others may still survive and provide a source of food security for the household. Similarly, in years of extensive crop failure (for example associated with floods or droughts) or livestock loss associated with outbreaks of livestock disease, diversified livelihood strategies mean that households have alternative income streams (e.g. from home based enterprises based on local value adding or beneficiation activities) to support them through challenging years. This diversification in livelihood strategies results in households being less resource dependent and more able to cope with the environmental shocks and extreme events arising from the impacts of climate change.

In years of favourable environmental and climatic conditions, households can enjoy the returns from productive and sustainable farming systems which are developed out of skills and capacity, appropriate technology, capital investment and guided by effective governance and policy. Well controlled land and resource use management means that the resilience of the environment is maintained. Long term planning horizons mean that there is a balance in the management of provisioning, regulating and supporting services and no tradeoffs are made that would have detrimental effects on ecosystem functioning in the long term.

Limited market opportunities mean that, despite the diversification and local value adding strategies undertaken by households, there is no ‘get rich quick’ scenario. However the impacts of climate change do not exacerbate poverty and households remain resilient and in a position to largely support their own livelihood needs.

Social and governance structures remain intact and effective and promote proactive policies and strategies to coping and adapting with the impacts of climate change and the consequential environmental and livelihood shocks.

## 6.3 Vulture Scenario

### Impacts on ecosystem functioning

The Vulture scenario highlights the disparities in access to finance for the "*haves*" and "*have-nots*". As with the other scenarios, more favourable conditions as a result of climate change is likely to improve food production overall. However, these benefits will be felt more by the "haves" who are cultivating high production areas than the "*have-nots*" who have been forced into marginal areas. In addition, improved yields for the "haves" coupled with the high poverty levels and risk of crop failure for the "*have-nots*" drives the need to cultivate the majority of the Capability Classes.

Increasing $CO_2$ levels is likely to favour woody species over grasses and thus an increase in shrublands and trees is anticipated. While this may provide additional year round fuel resources (compared to the seasonal fuel resources available under this scenario without climate change) and building material, the disparate access to resources may preclude the "*have-nots*" from benefiting from this change. In addition, the increase in shrublands and trees will occur in the grass communities resulting in a reduction in available grazing. The condition of these areas is also likely to deteriorate given the lack of effective governance and implementation of grazing management plans. While the increased cultivation may increase forage availability during the winter months, this does not provide an effective alternative to the previous year round grazing and is also susceptible to extreme events and crops failure.

The remaining grazing areas around the villages may therefore be designated to the "*haves*" forcing the "*have-nots*" to move their animals (which are likely to be in a poorer condition than those belonging to the "*haves*") into the highland areas for most of the year. The increase in extreme events as a result of climate change, coupled with the poor condition of these animals, may therefore result in increased mortality rates.

The cultivation of the majority of capability classes will exacerbate the projected loss of wetland functionality. Poor management of some areas coupled with the increased extent of cultivated lands and the projected increase of more intensive rainfall events will likely increase the opportunity for greater sediment deposition within low-lying wetlands and water bodies. The ability of these systems to function effectively will therefore be compromised negatively impacting water quality, streamflow regulation and sediment retention.

Regulating and supporting services are expected to decline significantly under this scenario and although climate change may provide minor improvements in the level of services available, the overall poor management and extensive loss of natural resources will result in a very fragile system (Figure 6.3.1 and 6.3.2).

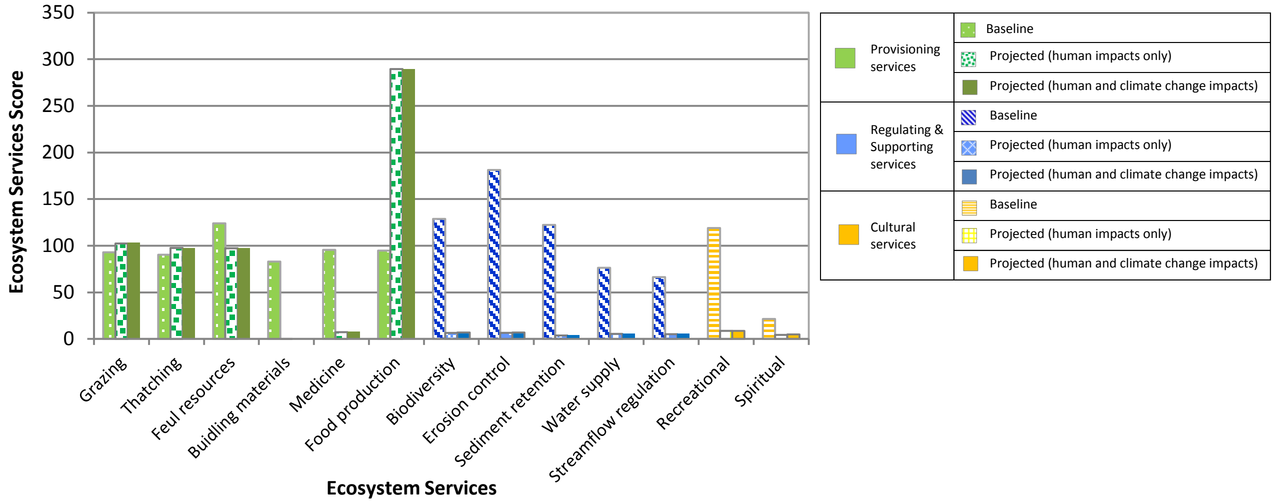



**Figure 6.3.1:** Projected change in ecosystem services at Muela under the Vulture Scenario as a result of anthropogenic factors and climate change

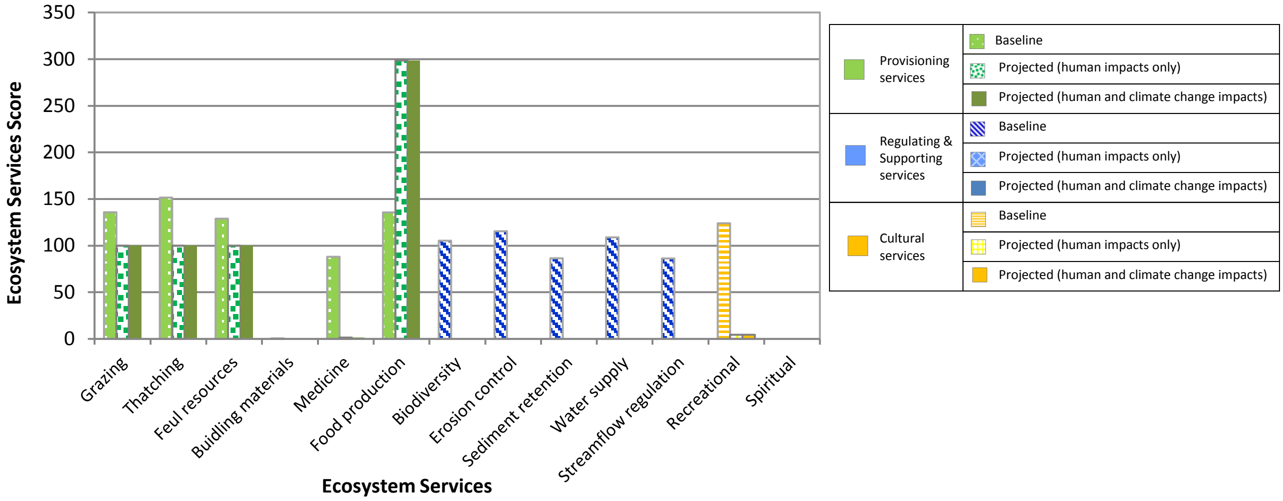



**Figure 6.3.2:** Projected change in ecosystem services at Sepinare under the Vulture Scenario as a result of anthropogenic factors and climate change

## Impacts on agriculture

Agriculture in this scenario is characterised by '*haves'* with seek to maximise short term production at the expense of long term sustainability and '*have nots*' who continue with their low input, low diversity subsistence production systems.

The commercially oriented '*haves*' invest in improved seed varieties and crop inputs (e.g.fertiliser, pesticides) to increase crop production. However there is limited investment in management factors that enhance long term sustainability of production, such as soil conservation measures, green manuring and crop rotation. Short term production is increased, but extremes of climate (particularly floods) causes increased land degradation and the loss of high potential land to soil erosion. The increased incidence of crop pests in controlled through chemical sprays, which are expensive and also have a negative effective on beneficial species. In the long term, soil fertility decreases and good arable land is lost due to soil erosion.

The subsistence '*have-nots'* do enjoy some benefits in production due to the increased rainfall and temperature, but the rates of soil erosion do increase as a result of extreme rainfall events. Over time, crop yields decrease, compounded by the increase in pests and disease. Food security for subsistence farmers is seriously compromised and many are forced to lease land to the commercial producers and work as labourers for the commercial farmers.

Large herds and flocks of livestock dominate the rangelands. With the warmer winter temperatures, more and more livestock remain in the highland cattle posts throughout the year. This places extreme pressure on the rangeland resources. Highlands are stripped bare of cover in winter and the spring rains bring widespread erosion and flooding due to the altered surface hydrology of the highland catchments. With poor animal vigour and limited management of the herds, disease outbreaks are common and devastating.

The net effect in this scenario is one of some short term gains by individuals, but a state of steady decline in production for most farmers. The gains in production come at the expense of the natural resource base, ultimately resulting in significant declines in production. In the end, food security is lost and all Highland households become extremely vulnerable to climate change.

## Livelihood trajectories and trade-offs

Livelihood diversification is only achieved by some households, the advantaged minority, who use their skills and access to finance to maximize the development and production opportunities available in the Highlands. The diversified livelihood strategies of these households reduce their direct dependency on the environment and primary agricultural production. This in turn helps to buffer them against the seasonality and shocks arising from impacts associated climate change. The more advantaged households are able to use their resources and reserves built up in good seasons to buffer themselves against the crop and livestock losses resulting for extreme events or bad seasons (e.g. droughts, floods). They are therefore able to recover faster than disadvantaged households and this helps to further strengthen their position of power and influence in the community, which they again use to manipulate resource management and land access in their favour. This increasingly breaks down social cohesion and collective action within villages to address challenges associated with climate change such as escalating environmental degradation.

This diversification of livelihood strategies and reduced dependency on the environment does not however encourage them to regulate and optimize their resource use to conserve the environment. Conversely, because of the uncertainty associated with climate change, ineffective governance and a lack of policy, these households adopt a very short term planning horizon and attempt to maximize whatever benefits they can from the environments provisioning services, at the expense of provisioning and regulating services. While short term returns are relatively high, the negative consequences for long term ecosystem functioning compromises the sustainability of these benefits. Households' strategies are therefore to attempt to build up sufficient resources and incomes to assist them to migrate out of the Highlands to areas that offer livelihood opportunities that are more secure and less susceptible and vulnerable to the impacts of climate change (i.e. less resource dependent). When households are able to achieve this, it compounds the outflow of skills and resources from the Highlands.

Disadvantaged households are marginalized further and further, both as a result of livelihood shocks and losses associated with impacts of climate change as well as losing access to land and resources in favour of the disadvantaged minority. Due to a lack of capacity and access to resources the disadvantaged households are unable to diversify their livelihood strategies and become increasingly vulnerable as returns from primary agriculture and resource use decline. These households therefore attempt to cope and maintain their livelihood resilience by sending family members away to look for work in towns or to work as labour and herders for the more advantaged households locally. However, while this may result in a small income to the family, the household's labour base is weakened. Illness and frailness increasingly characterizes the condition of families as they find it increasingly difficult to meet basic food, energy and health needs. This, together with the weakened family labour base compromises their ability to farm crops and livestock effectively. There is an increase in the frequency of crop failures and livestock loss to extreme climatic events and these households too resort to maximizing short term provisioning benefits from the environment at unsustainable levels.

The compromised state of disadvantaged households and the self-serving behavior of the relatively advantaged households result in a complete breakdown in social cohesion and collective action. The tragedy of the commons scenario becomes entrenched with the maximisation of short term resource use by all households to meet their own self-interests takes place the expense of long-term sustainability. There is no investment in environmental rehabilitation and human pressures drive the degradation of ecosystem functioning to a point that it compromises essential ecological services upon which the households in the Highlands depend. While the impacts will be very high the consequences will probably only be fully felt and understood when these losses have already occurred, and will probably be irreversible. This will ultimately have dire consequences for households living in these areas, as well as for downstream (in the lowlands of Lesotho as well as South Africa), who also benefit and rely on the ecosystem services generated in the Highlands.

## 6.4 Jackal Scenario

**Impacts on ecosystem functioning**

The Jackal scenario is characterized by high levels of poverty and lack of governance thereby placing significant pressure on natural resources and the environment. As with the other scenarios, increases in temperature and precipitation is likely to result in increases in food production, however access to resources and skills limits inputs and management thereby reducing potential yields. The risk of crop failure also increases as a result of climate change. High levels of poverty coupled with the risk of crop failure increase the need of households to cultivate Capability Classes I to VIII.

While shrublands, trees and streambank vegetation is set to increase as a result of increased $CO_2$ concentrations, thereby increasing the potential availability of fuel resources and building materials, the cultivation of all available areas negates this benefit. Similarly, grazing areas decrease significantly as a result of transformation rather than climate change and households are only left with seasonal fodder in the form of stover available from cultivated fields. The availability of this fodder material is even more intermittent under this scenario when considering climate change, as crop failure may reduce its availability. Thus livestock may be forced to spend winter months in the Highlands in search of food, exposing them to extreme events and increasing their mortality.

The conversion of wetlands to agriculture coupled with inappropriate management of the transformed areas will result in biodiversity loss, increased soil erosion and reductions in streamflow regulation and water supply. The quality of water entering water bodies in the catchments will be severely compromised.

The transformation of virtually all natural areas to cultivation results in a significant decline in regulating and supporting services and a general seasonal shift in provisioning services (Figure 6.4.1 and 6.4.2). This loss in regulating and supporting services undermines the ability of ecosystems to function effectively and decreases their resilience.

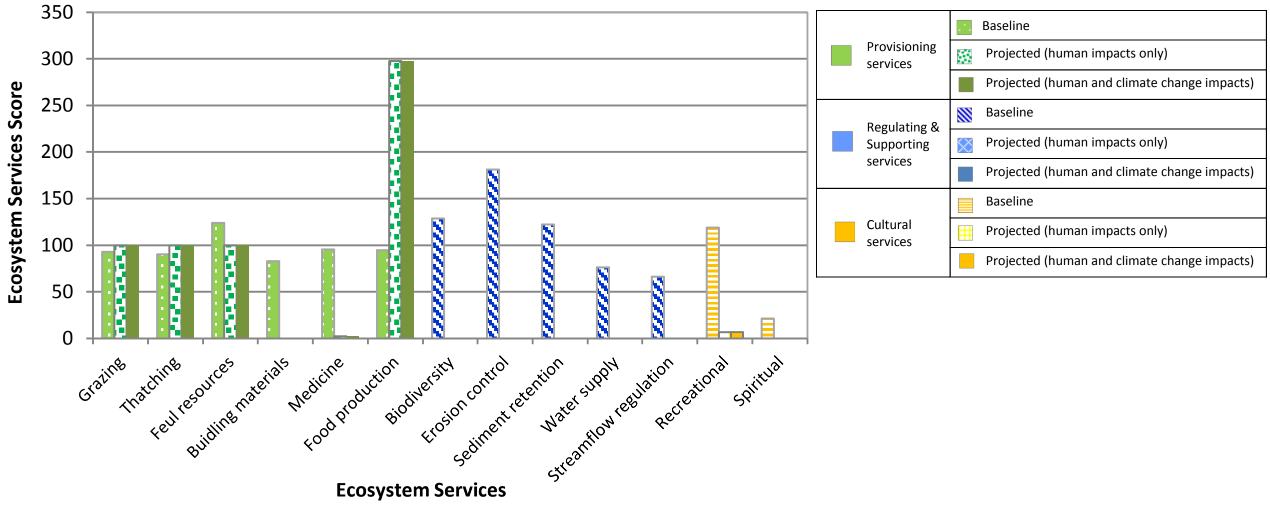



**Figure 6.4.1:** Projected change in ecosystem services at Muela under the Jackal Scenario as a result of anthropogenic factors and climate change

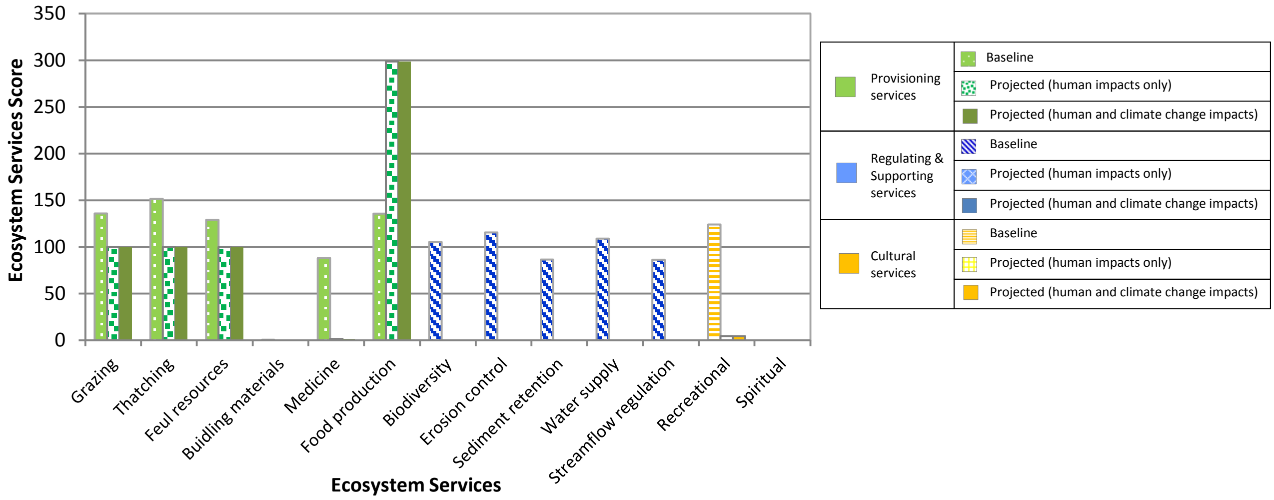



**Figure 6.4.2:** Projected change in ecosystem services at Sepinare under the Jackal Scenario as a result of anthropogenic factors and climate change

## Impacts on agriculture

Undiversified agricultural production systems characterised by low levels of inputs and limited production technologies dominate.

Crop production, facing a slow but steady decline under current climatic conditions, is faced with accelerated decline under future climate scenarios. Soil conservation structures established in the twentieth century are steadily washed away by the increasingly prevalent extreme rainfall events and large volumes of topsoil are lost from productive lands. Due to the loss of soil water holding capacity, much rainfall on the soil is lost as surface runoff and is not available to the plants for growth. Declining soil fertility further decreases production and is exacerbated by more frequent pest and disease outbreaks. Farmers are forced to enter into a 'slash-and-burn' production system, using highly fragile soils to produce crops in the short term.

The loss of grazing land to cropping, combined with the maximisation of livestock by all households, places significant pressure on the grazing resources. The vigour and condition of livestock is extremely poor and outbreaks of disease are common. Cattle are particularly vulnerable to new diseases and most are lost. This further limits the ability of highland communities to feed themselves with crops as they have to prepare their land by hand.

The net result of this is seriously compromised food security and great vulnerability to climate change.

## Livelihood trajectories and trade-offs

Due to a lack of capacity and access to resources households are unable to diversify their livelihood strategies and become increasingly vulnerable as returns from primary agriculture and resource use decline. A lack of social cohesion and structure prevents any coordinated resource and land management, planning and rehabilitation. Households therefore attempt maximize their personal crop areas and resource harvesting. This self-serving behavior of the households entrenches the tragedy of the commons scenario with the maximisation of short term resource use by all households to meet their own self-interests takes place the expense of long-term sustainability.

Despite these efforts to maximize returns from primary production, crop yields and livestock production continue to decline and to cope and maintain their livelihood resilience by sending family members away to look for work in towns or to work as labour and herders for the more advantaged households locally. However, while this may result in a small income to the family, the household's labour base is weakened. Illness and frailness increasingly characterizes the condition of families as they find it increasingly difficult to meet basic food, energy and health needs. This, together with the weakened family labour base compromises their ability to farm crops and livestock effectively. There is an increase in the frequency of crop failures and livestock loss due to extreme climatic events and the increasing seasonality of benefits from ecosystem services. There is therefore much higher dependency on outside support for food aid and welfare as households' resilience is eroded and they are no longer sure of even meeting their own basic food security needs.

There is no investment in environmental rehabilitation and human pressures drive the degradation of ecosystem functioning to a point that it compromises essential ecological services upon which people depend. While the impacts will be very high the consequences will probably only be fully felt and understood when these losses have already occurred, and will probably be irreversible. This will ultimately have dire consequences for households living in these areas, as well as for downstream (in the lowlands of Lesotho as well as South Africa), who also benefit and rely on the ecosystem services generated in the Highlands.

# 7 CONSTRAINTS AND OPPORTUNITIES FOR ADAPTATION

## 7.1 Ecosystems

**Key vulnerabilities for ecosystems and livelihoods**

Key driving forces for projected change to ecosystems and livelihoods include land transformation and climate change. Land transformation is largely affected by governance and social structures, and economic opportunities. These two key driving forces are likely to play a major role in contributing to ecosystem vulnerability. Without the implementation of sustainable land management practices, land transformation will result in an overall loss of ecosystems and their associated services. The loss of provisioning services is of great concern for the communities living in the Highlands, and the loss of supporting and regulating services are of particular concern for the supply of quality water to water bodies within the catchments. In addition, an overall loss of ecosystems will lead to the loss of biodiversity. Climate change coupled with the effect of unsustainable land management practices could likely result in a reduction in wetland functionality, loss of climax grasslands, and the loss of biodiversity or more specifically the loss of endemic species within high-lying areas. Therefore key ecosystem vulnerabilities include:

- All ecosystems should sustainable land management practices not be implemented;
- Wetland functionality;
- Climax grasslands; and
- Endemic species occurring within the Afro-alpine grassland zone.

**Constraints and opportunities for adaptation**

Constraints for adapting to climate change are largely within governance and social structures. These primarily include the wiliness, or lack thereof, of communities and authorities to change, and the perception of risk associated with adapting when there are limited alternatives that could potentially reduce risk. Communities lack of wiliness to accept adaptation may be because of the perception of change being too risky and that it is safer to stick with what is known and rather develop coping mechanism when required. The concern of the lack of economic alternatives is a major constraint as under the scenarios it is only the Rabbit scenario where there are likely to be economic alternatives, which would reduce the risk of adaptation.

Opportunities for adaptation could be the direct opposite to constraints identified. As there is likely to be a lack of wiliness to change there is an opportunity for governance structures to be developed that will better facilitate change. Likewise the lack of economic alternatives provides an opportunity to identify potential alternatives.

## 7.2 Agriculture

The implications of climate change under current agricultural production systems are significant. Reduced crop yields and increased risk of crop failure due to a shorter growing season, reduced effective rainfall and higher incidence of drought are likely to become more frequent. Current crop production systems, which are characterised by low input, low diversity, mono-cropping systems with inadequate erosion control measures increase vulnerability significantly.

Similarly with livestock, there is likely to be a decrease in forage production and a decline in the carrying capacity of the rangelands. This will have negative impacts on livestock production resulting in reduced animal vigour and fertility. As animal condition deteriorates, the quality of animal products especially wool will decline. Furthermore there will be a higher incidence of pests and diseases which will have negative implications for animal production.

On the other hand, higher temperatures and higher rainfall can be taken advantage of and used to enhance production. This requires the establishment of good agricultural management systems that can take advantage of these predicted changes in climate.

Major opportunities for enhancing crop production are:

- Diversification of crop production from a maize based system to a grain, pulse and legume production system as well as agroforestry and intercropping
- Invest in improved open pollinated crop varieties that are best suited to the production environment.
- Crop rotation and fallow land to increase soil fertility, organic content and limit the spread of disease
- Establish sound and integrated soil conservation systems (contours, bunds and waterways) to eliminate soil erosion.
- Develop in-field and household water harvesting systems that increase infiltration, reduce runoff and store water.

For livestock production, it is necessary to firstly place control on the numbers of livestock and reduce stocking rates to aid the recovery of rangelands. The strong cultural ties to the keeping of livestock as an indicator of wealth are a major constraint to reducing livestock numbers and consequently adaptation to climate change from a rangeland management perspective. This will require clear and implementable policies on livestock control and management. Incentive based systems to encourage compliance should be established backed up with a commitment to enforcement should there be non-compliance.

## 7.3 Livelihoods

High poverty levels and a shortage of skills and capacity already make the households of the Highlands very vulnerable, even without the impacts of climate change. Short term needs to address poverty at a household level are already leading households to maximise the provisioning services from the ecosystem at the expense of long term provisioning and supporting services. The trends in environmental degradation are already evident, and the carrying capacity of the rangelands for livestock is already recognized as deteriorating while yields from crop production are also widely recognized as declining. These trends indicate that the resilience of the livelihoods of the resource dependent communities in the Highlands is already being eroded and vulnerability levels are increasing. The increasing seasonality in ecosystem services and shocks anticipated in association with climate change will exacerbate these risks and vulnerabilities.

But if households in the Highlands are already (as a result of relatively high poverty levels) in a position where they cannot themselves to break the dependency on traded off short term provisioning services against long term regulating and supporting services, then how will they be able to improve their coping and adaptation capacity to deal with climate change in future?

Interventions that address the following three factors will likely be the best opportunities for addressing resilience against climate change:

- Capacity building and awareness - to improve sustainable land management. Improved land management will enhance ecosystem functioning and the generation of the full suite of ecosystem services which will improve the resilience of local livelihoods beyond the benefits associated with any individual climate adaptation strategy.
- Effective governance – effective governance includes proactive and effective national policy environment to guide local development and actions, as well as effective district and traditional governance and leadership systems to ensure the rules and controls are implemented. This includes informing and promoting improved agricultural systems as well as providing incentives for sustainable environmental management and rehabilitation.
- Livelihood diversification – The diversification of livelihood strategies to facilitate a move away from largely resource dependent activities will likely help to address poverty as well as reduce the vulnerability of households to the impacts of climate change which will impact most on primary agricultural production and use of natural resources.

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# Appendix A

| Vegetation Community / Land Cover Class | Vegetation Type | Sesotho Name | Dominant Species (Herbaceous Layer) | Grazing Capacity (ha/LSU) | Pilot Site | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Muela | Setibi | Sepinare | Koporale |
| **Themeda-Festuca Grassland** | *Themeda-Festuca* Climax Grassland | Sebuko-Letsiri | *Themeda triandra*<br>*Festuca caprina*<br>*Merxmuellera disticha* | 5 | 72.22 | 148.52 | 36.72 | 230.97 |
| | *Themeda-Heteropogon-Trachypogon Dry Climax Grassland* | Sebuko-Selokane | *Themeda triandra*<br>*Heteropogon contortus*<br>*Trachypogon spicatus*<br>*Aristida junciformis* | 10 | | 24.93 | 89.76 | 63.61 |
| | *Festuca-Pentaschistis-Themeda* Sub-Alpine Grassland | Letsiri | *Festuca caprina*<br>*Pentaschistis setifolia*<br>*Koeleria capensis*<br>*Merxmuellera disticha*<br>*Themeda triandra* | 5 | 143.10 | 32.75 | 3.06 | |
| **Aristida-Eragrostis-Artemesia Degraded Grasslands** | *Aristida-Helictotrichon* Moist Grassland | Lefielo-Mosuhela | *Aristida junciformis*<br>*Helictotrichon turgidulum*<br>*Eragrostis curvula* | 10 | 19.17 | | | |
| | *Aristida-Pentzia-Felicia muricata* Eroded Grassland | Lekhulo le lebe | *Aristida diffusa*<br>*Eragrostis chloromelas*<br>*Felicia muricata* | 16 | | 42.92 | 122.27 | 234.55 |
| | *Eragrostis chloromelas-Aristida junciformis* Degraded Grassland | Lekhulo le lebe | *Eragrostis curvula*<br>*Eragrostis plana*<br>*Aristida junciformis* | 13 | | 48.91 | | |
| | *Artemisia-Eragrostis* Degraded Grassland | Lengane-Tsane | *Artemisia afra*<br>*Eragrostis curvula* | 13 | | 122.03 | 187.00 | 259.68 |

| Vegetation Community / Land Cover Class | Vegetation Type | Sesotho Name | Dominant Species (Herbaceous Layer) | Grazing Capacity (ha/LSU) | Pilot Site | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Muela | Setibi | Sepinare | Koporale |
| | | | *Themeda triandra*<br>*Aristida junciformis*<br>*Koeleria capensis*<br>*Helictotrichon* species | | | | | |
| **Harpochloa Grasslands** | *Harpochloa-Eragrostis-Themeda* Short Grassland | Lefokolodi-Sebuko | *Harpochloa falx*<br>*Eragrostis capensis*<br>*Themeda triandra* | 10 | 0.52 | 11.27 | 47.83 | 227.83 |
| | *Harpochloa falx-Catalepis gracilis Short Grassland* | Lefokolodi | *Harpochloa falx*<br>*Eragrostis chloromelas*<br>*Catalepis gracilis* | 13 | 37.55 | 34.96 | 54.44 | 204.63 |
| **Felicia – Chrysocoma Shrubland** | *Felicia filifolia-Pentzia-Chrysocoma* Shrubland | Sehalahala | *Andropogon ravus*<br>*Felicia filifolia*<br>*Pentzia cooperi* | 11 | 138.72 | | | |
| | *Chrysocoma-Pentzia-Helichrysum* Shrubland | Sehalahala | *Chrysocoma ciliata*<br>*Pentzia cooperi*<br>*Helichrysum odoratissimum*<br>*Eragrostis chloromelas* | 15 | | 52.52 | | |
| | *Passerina-Chrysocoma* Heathland | Lekhapu | *Passerina montana*<br>*Chrysocoma ciliata* | 15 | | | | |
| | Short Shrublands-*Helichrysum* (<1.5m) | Phefo-Hukobetsi | *Helichrysum trilineatum*<br>*Helichrysum odoratissimum* | 15 | | | | |
| **Alpine Grassland (Festuca)** | Summit Alpine Grassland | Limela tse ka holima Lithaba | *Festuca caprina*<br>*Pentaschistis setifolia*<br>*Koeleria capensis*<br>*Merxmuellera disticha* | 10 | 39.64 | | | |

<table>
<tr><th rowspan="2">Vegetation Community / Land Cover Class</th><th rowspan="2">Vegetation Type</th><th rowspan="2">Sesotho Name</th><th rowspan="2">Dominant Species (Herbaceous Layer)</th><th rowspan="2">Grazing Capacity (ha/LSU)</th><th colspan="4">Pilot Site</th></tr>
<tr><th>Muela</th><th>Setibi</th><th>Sepinare</th><th>Koporale</th></tr>
<tr><td></td><td>Slope Alpine Grassland</td><td>Limela tse ka holima Lithaba</td><td>Festuca caprina<br>Pentaschistis setifolia<br>Koeleria capensis<br>Merxmuellera disticha<br>Harpochloa falx</td><td>10</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Hyparrenhia Grasslands</td><td>Hyparrhenia-Andropogon Tall Grassland</td><td>Mohlomo</td><td>Hyparrhenia hirta<br>Andropogon ravus<br>Eragrostis curvula<br>Aristida junciformis</td><td>10</td><td>81.84</td><td></td><td></td><td></td></tr>
<tr><td>Hyparrhenia-Felicia Degraded Grassland</td><td>Mohlomo</td><td>Hyparrhenia hirta<br>Aristida diffusa<br>Catalepis gracilis<br>Microchloa caffra<br>Felicia filifolia</td><td>11</td><td>399.94</td><td></td><td></td><td></td></tr>
<tr><td>Hyparrhenia-Felicia Eroded Grassland</td><td>Lekhulo le lebe</td><td>Hyparrhenia hirta<br>Aristida diffusa<br>Felicia filifolia</td><td>11</td><td>37.15</td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">Rocklands/Rocksheets</td><td>Cymbopogon-Felicia Rock Terraces/Rocklands</td><td>Lebate-Sehalahala</td><td>Cymbopogon pospischilii<br>Felicia filifolia<br>Aristida junciformis</td><td>27</td><td>0.85</td><td>8.44</td><td>38.10</td><td>20.37</td></tr>
<tr><td>Cliff Vegetation</td><td>Lilomo</td><td></td><td>0</td><td>139.77</td><td>1.47</td><td></td><td>19.75</td></tr>
<tr><td>Sub-alpine Rocksheet</td><td>Lekhoara</td><td>Catalepis gracilis<br>Aristida diffusa<br>Digitaria eriantha</td><td>27</td><td>123.08</td><td rowspan="2">60.34</td><td rowspan="2">24.19</td><td rowspan="2">126.02</td></tr>
<tr><td>Foothills Rocksheets</td><td>Lekhoara</td><td>Andropogon ravus,<br>Catalepis gracilis</td><td>27</td><td>125.62</td></tr>
</table>

| Vegetation Community / Land Cover Class | Vegetation Type | Sesotho Name | Dominant Species (Herbaceous Layer) | Grazing Capacity (ha/LSU) | Pilot Site | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Muela | Setibi | Sepinare | Koporale |
| | | | *Xerophyta viscosa* | | | | | |
| | Sandstone Grassland | Limela tse lesehloeng | | 11 | 71.32 | | | |
| **Leucosidea Shrubland** | *Leucosidea sericea* Closed Shrubland | Cheche | *Aristida junciformis*<br>*Eragrostis curvula*<br>*Helictotrichon turgidulum* | 30 | 355.84 | | | |
| | *Leucosidea sericea* Open Shrubland | Cheche | *Hyparrhenia hirta*<br>*Aristida junciformis*<br>*Eragrostis curvula* | 12 | 196.66 | | | |
| **Buddleia Shrubland** | *Buddleia salviifolia* Riverine Shrubland | Lelothoane | *Buddleia salviifolia* | 12 | 177.50 | | | |
| **Trees (Poplar)** | Planted Plantations | Moru | | 0 | | | | |
| | *Populus* Plantations | Moru | | 0 | 4.03 | 8.36 | 2.50 | 0.38 |
| **Settlement & Infrastructure** | Settlements | Motse | *Catalepis gracilis*<br>*Eragrostis chloromelas*<br>*Eragrostis plana*<br>*Felicia muricata*<br>*Bromus* species<br>*Pennisetum clandestinum*<br>*Cynodon* species | 15 | 127.22 | 61.25 | 28.44 | 80.01 |
| | Roads | Litsela | | 0 | 7.29 | 14.59 | 7.28 | 30.28 |
| | Roadside Vegetation | Lekhulo le lebe | | 15 | | 1.39 | | 18.53 |
| | LHDA Infrastructure | LHDA | | 0 | | | | |
| **Streambank Vegetation (Salix)** | Streambank Vegetation | Limela tse mabopong | | 10 | 61.49 | 10.77 | | 13.54 |

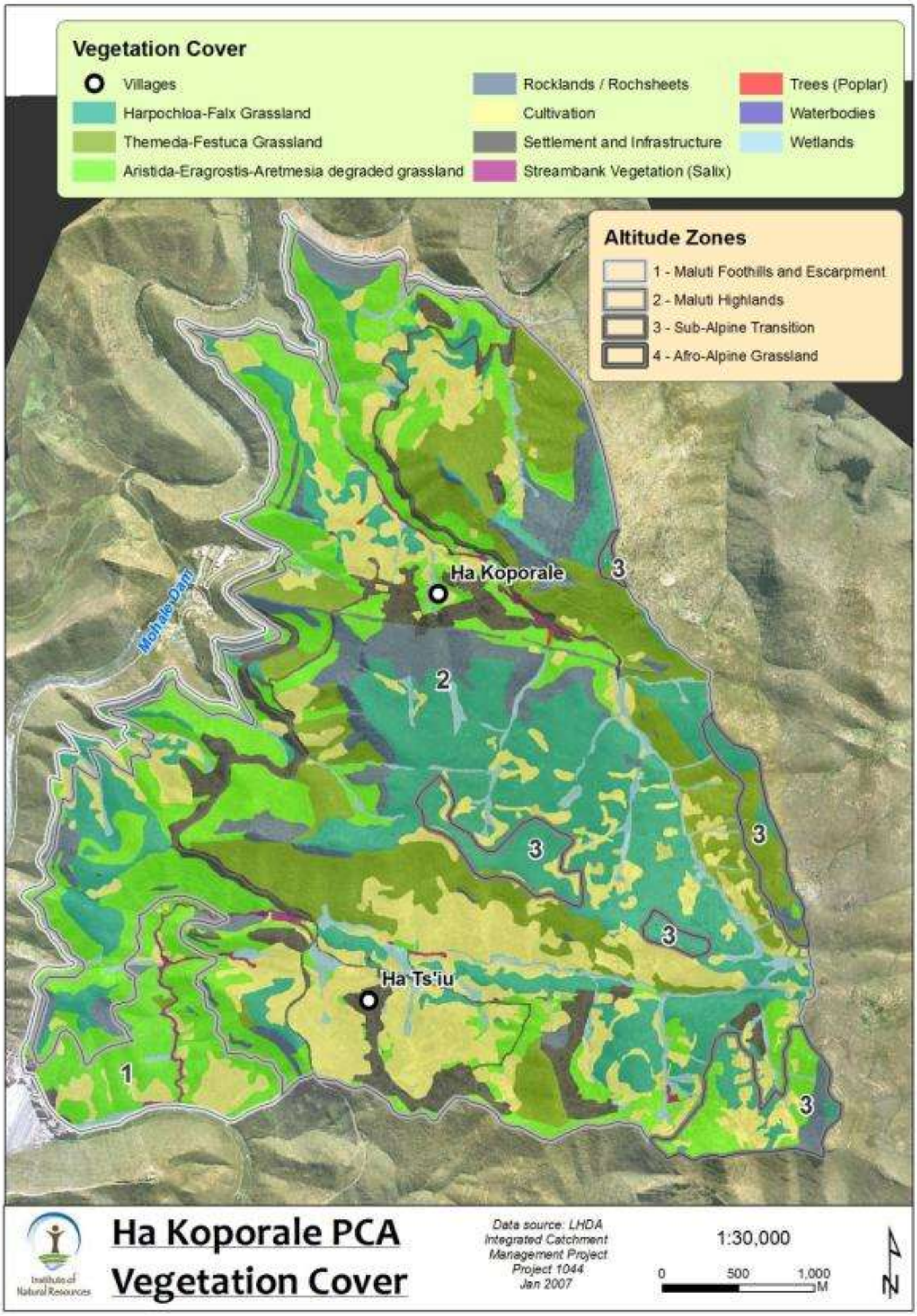
| Vegetation Community / Land Cover Class | Vegetation Type | Sesotho Name | Dominant Species (Herbaceous Layer) | Grazing Capacity (ha/LSU) | Pilot Site | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Muela | Setibi | Sepinare | Koporale |
| **Wetlands** | *Merxmuellera*-Seepage Grassland | Molalahlolo | *Merxmuellera macowanii* | 40 | | | | |
| | Wetlands | Makhulo | *Fingerhuhtia sesleriiformis*<br>*Eragrostis planiculmis*<br>*Agrostis lachnantha*<br>*Sedge species* | 6 | 41.60 | 41.24 | 38.47 | 81.65 |
| **Cultivation** | Cultivation | Masimo | | 30 | 450.12 | 290.23 | 336.19 | 397.54 |
| | Tall Shrubland-*Rhus, Rosa* (>1.5m) | Kolitsane | | 15 | | 11.08 | | |

** Areas provided are approximate areas obtained from the vegetation assessment undertaken for the ICM project (SMEC, 2010b).*

# Appendix B

| **Vegetation Communities** | **Rules applied to identify suitable landscape features for the projected expansion of vegetation communities as a result of climate change** |
|---|---|
| **Alpine grasslands** | |
| Aspect | All |
| Altitude | >2850m |
| Slope | 0-20° |
| Proximity to drainage line: | N/A |
| **Felicia shrublands** | |
| Aspect | North West, South East |
| Altitude | >2100m |
| Slope | >20° |
| Proximity to drainage line: | N/A |
| **Leucosidea shrubland** | |
| Aspect | South, South West, West |
| Altitude | 1800-2500m |
| Slope | 20-30° |
| Proximity to drainage line: | N/A |
| **Buddleja shrubland** | |
| Aspect | North East, East, South West, West |
| Altitude | < 2500m |
| Slope | 10-20° |
| Proximity to drainage line: | Within 35m |
| **Trees** | |
| Aspect | North, North East, East, South East, South |
| Altitude | < 2250m |
| Slope | 0 - 20° |
| Proximity to drainage line: | Within 35m |
| **Streambank vegetation** | |
| Aspect | North, North East, East, South East, South |
| Altitude | All |
| Slope | 0 - 20° |
| Proximity to drainage line: | Within 20m |

# Appendix C



Vegetation Cover
Villages
Harpochloa-Falx Grassland
Themeda-Festuca Grassland
Aristida-Eragrostis-Aretmesia degraded grassland
Rocklands / Rochsheets
Cultivation
Settlement and Infrastructure
Streambank Vegetation (Salix)
Trees (Poplar)
Waterbodies
Wetlands
Altitude Zones
1 - Maluti Foothills and Escarpment
2 - Maluti Highlands
3 - Sub-Alpine Transition
4 - Afro-Alpine Grassland
Ha Koporale
Mohale Dam
Ha Ts'iu
Ha Koporale PCA
Vegetation Cover
Institute of Natural Resources
Data source: LHDA
Integrated Catchment
Management Project
Project 1044
Jan 2007
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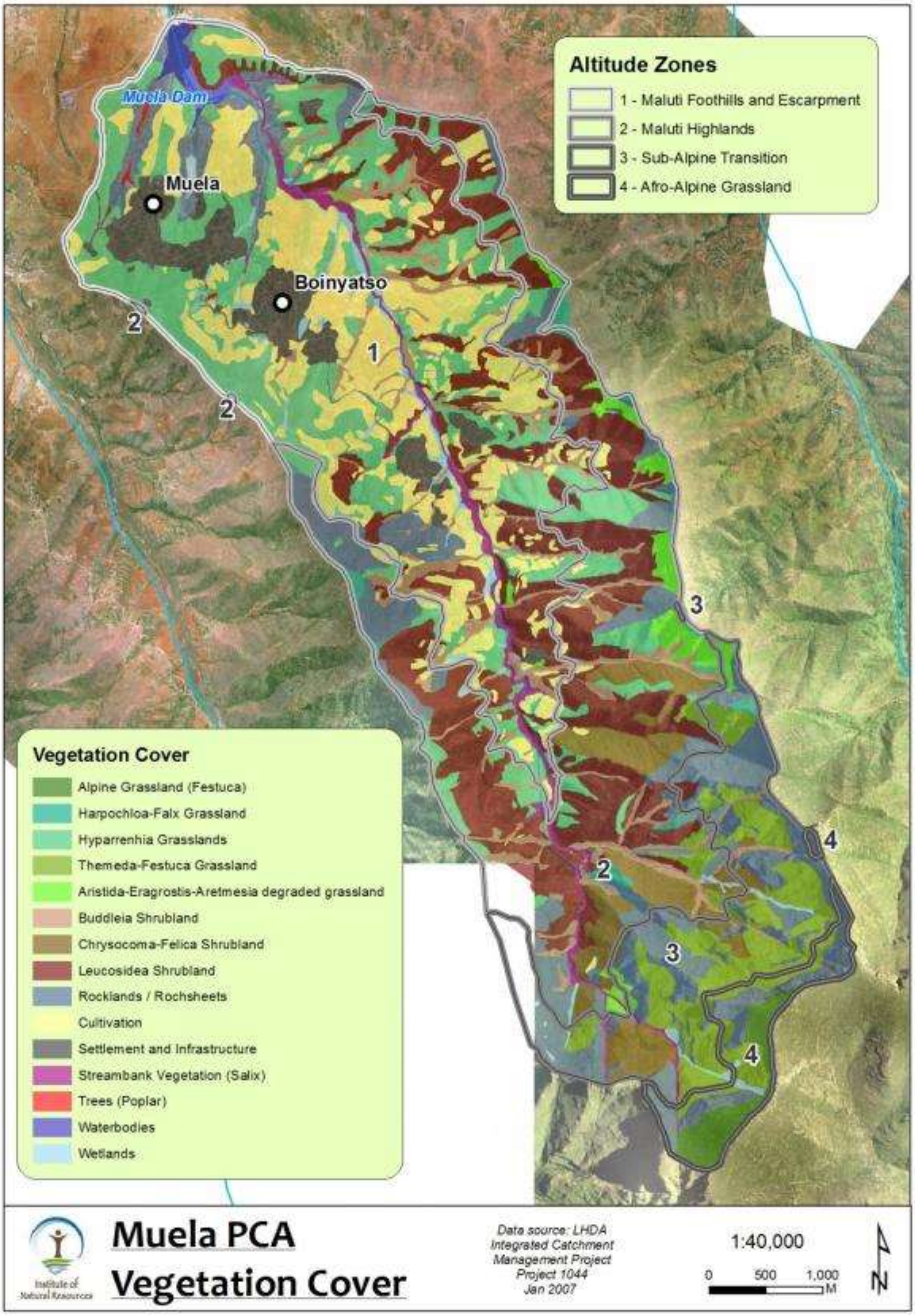
Altitude Zones
1 - Maluti Foothills and Escarpment
2 - Maluti Highlands
3 - Sub-Alpine Transition
4 - Afro-Alpine Grassland
Muela Dam
Muela
Boinyatso
Vegetation Cover
Alpine Grassland (Festuca)
Harpochloa-Falx Grassland
Hyparrenhia Grasslands
Themeda-Festuca Grassland
Aristida-Eragrostis-Aretmesia degraded grassland
Buddleia Shrubland
Chrysocoma-Felica Shrubland
Leucosidea Shrubland
Rocklands / Rochsheets
Cultivation
Settlement and Infrastructure
Streambank Vegetation (Salix)
Trees (Poplar)
Waterbodies
Wetlands
Muela PCA
Vegetation Cover
Data source: LHDA
Integrated Catchment
Management Project
Project 1044
Jan 2007
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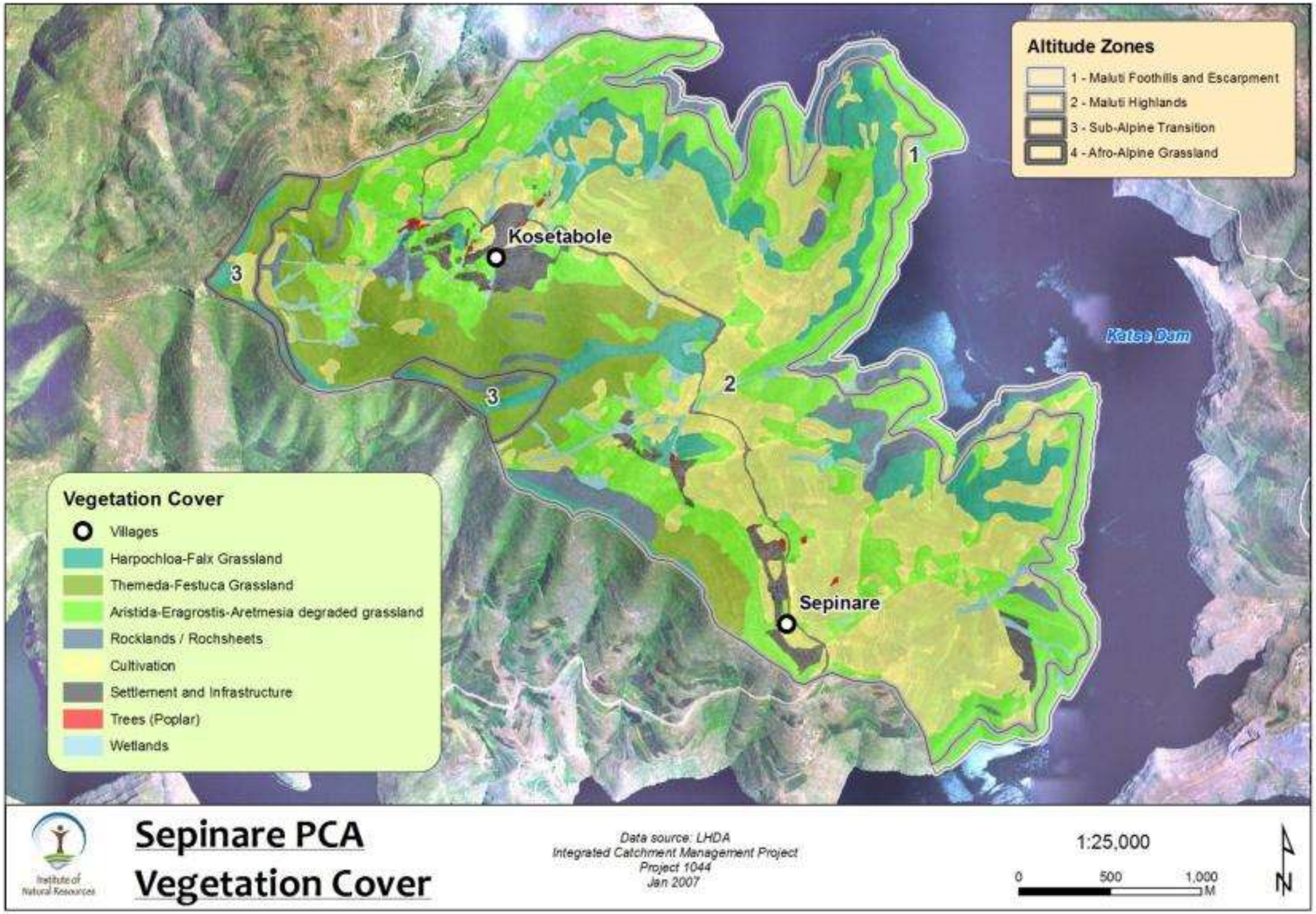
N


Altitude Zones
1 - Maluti Foothills and Escarpment
2 - Maluti Highlands
3 - Sub-Alpine Transition
4 - Afro-Alpine Grassland
Kosetabole
Sepinare
Katse Dam
1
2
3
3
Vegetation Cover
Villages
Harpochloa-Falx Grassland
Themeda-Festuca Grassland
Aristida-Eragrostis-Aretmesia degraded grassland
Rocklands / Rochsheets
Cultivation
Settlement and Infrastructure
Trees (Poplar)
Wetlands
Sepinare PCA
Vegetation Cover
Data source: LHDA
Integrated Catchment Management Project
Project 1044
Jan 2007
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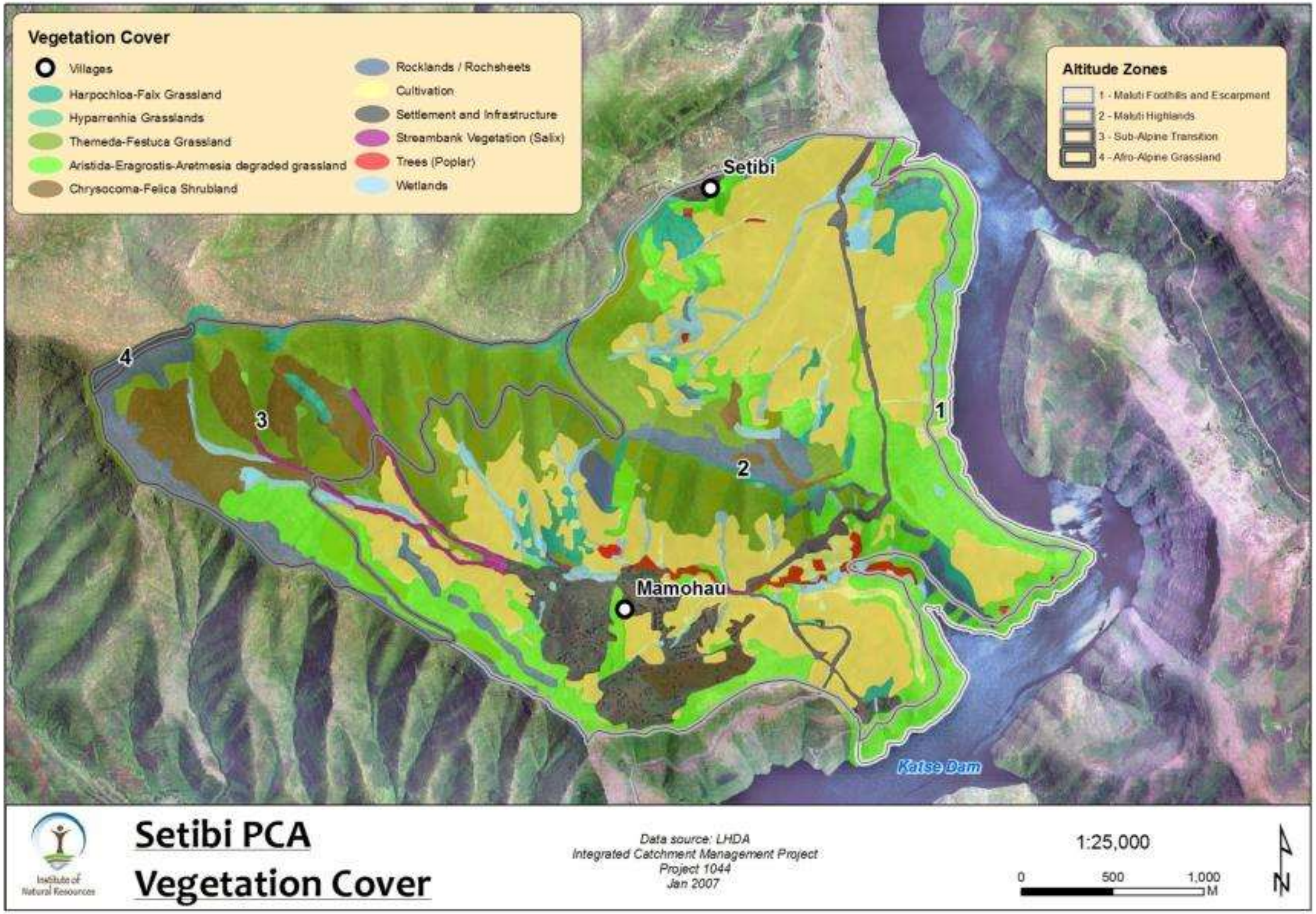

Vegetation Cover
Villages
Harpochloa-Falx Grassland
Hyparrenhia Grasslands
Themeda-Festuca Grassland
Aristida-Eragrostis-Aretmesia degraded grassland
Chrysocoma-Felica Shrubland
Rocklands / Rochsheets
Cultivation
Settlement and Infrastructure
Streambank Vegetation (Salix)
Trees (Poplar)
Wetlands
Altitude Zones
1 - Maluti Foothills and Escarpment
2 - Maluti Highlands
3 - Sub-Alpine Transition
4 - Afro-Alpine Grassland
Setibi
Mamohau
1
2
3
4
Katse Dam
Institute of Natural Resources
Setibi PCA
Vegetation Cover
Data source: LHDA
Integrated Catchment Management Project
Project 1044
Jan 2007
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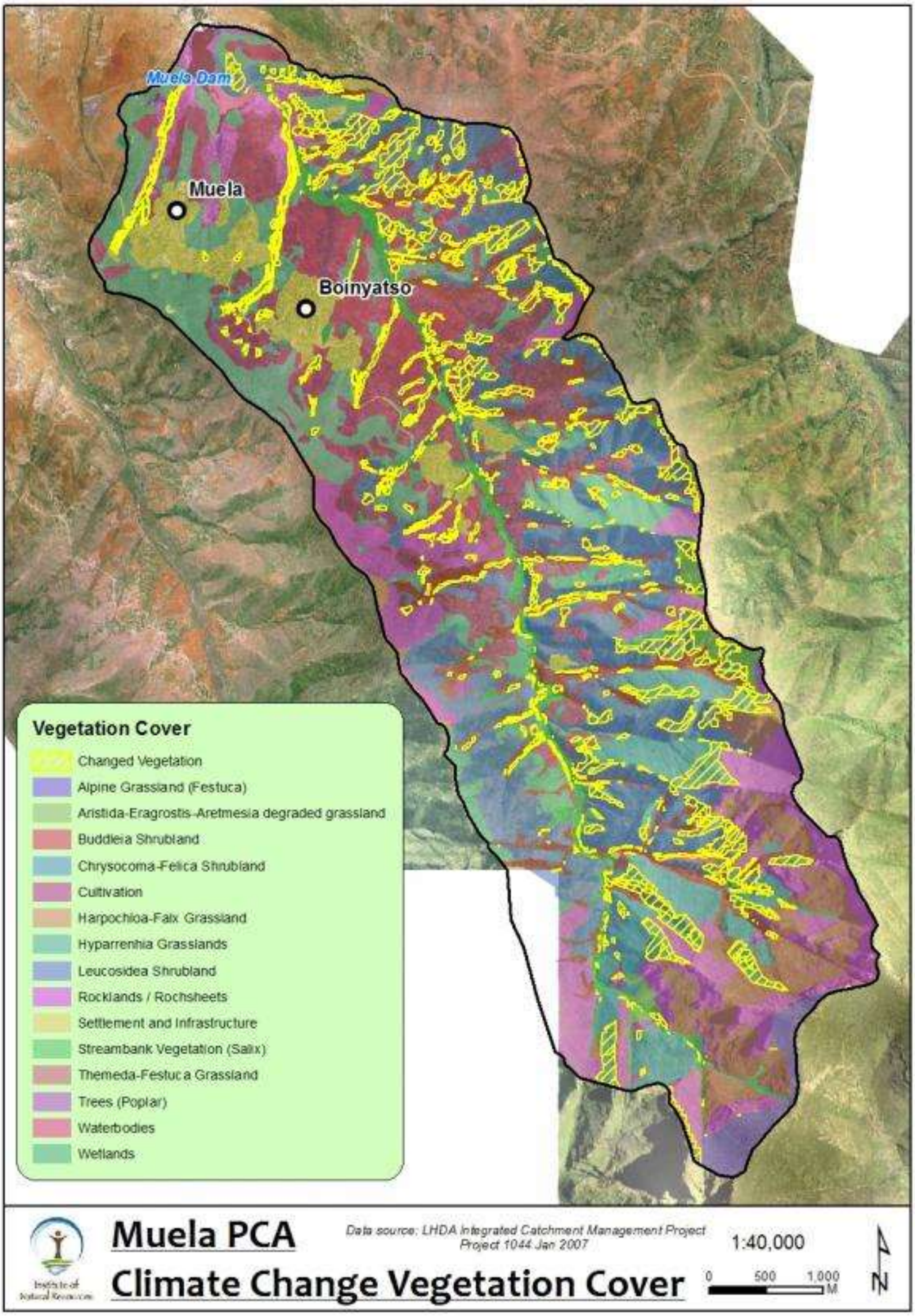
# Appendix D


Muela Dam
Muela
Boinyatso
Vegetation Cover
Changed Vegetation
Alpine Grassland (Festuca)
Aristida-Eragrostis-Aretmesia degraded grassland
Buddleia Shrubland
Chrysocoma-Felica Shrubland
Cultivation
Harpochloa-Falx Grassland
Hyparrenhia Grasslands
Leucosidea Shrubland
Rocklands / Rochsheets
Settlement and Infrastructure
Streambank Vegetation (Salix)
Themeda-Festuca Grassland
Trees (Poplar)
Waterbodies
Wetlands
Muela PCA
Climate Change Vegetation Cover
Data source: LHDA Integrated Catchment Management Project
Project 1044 Jan 2007
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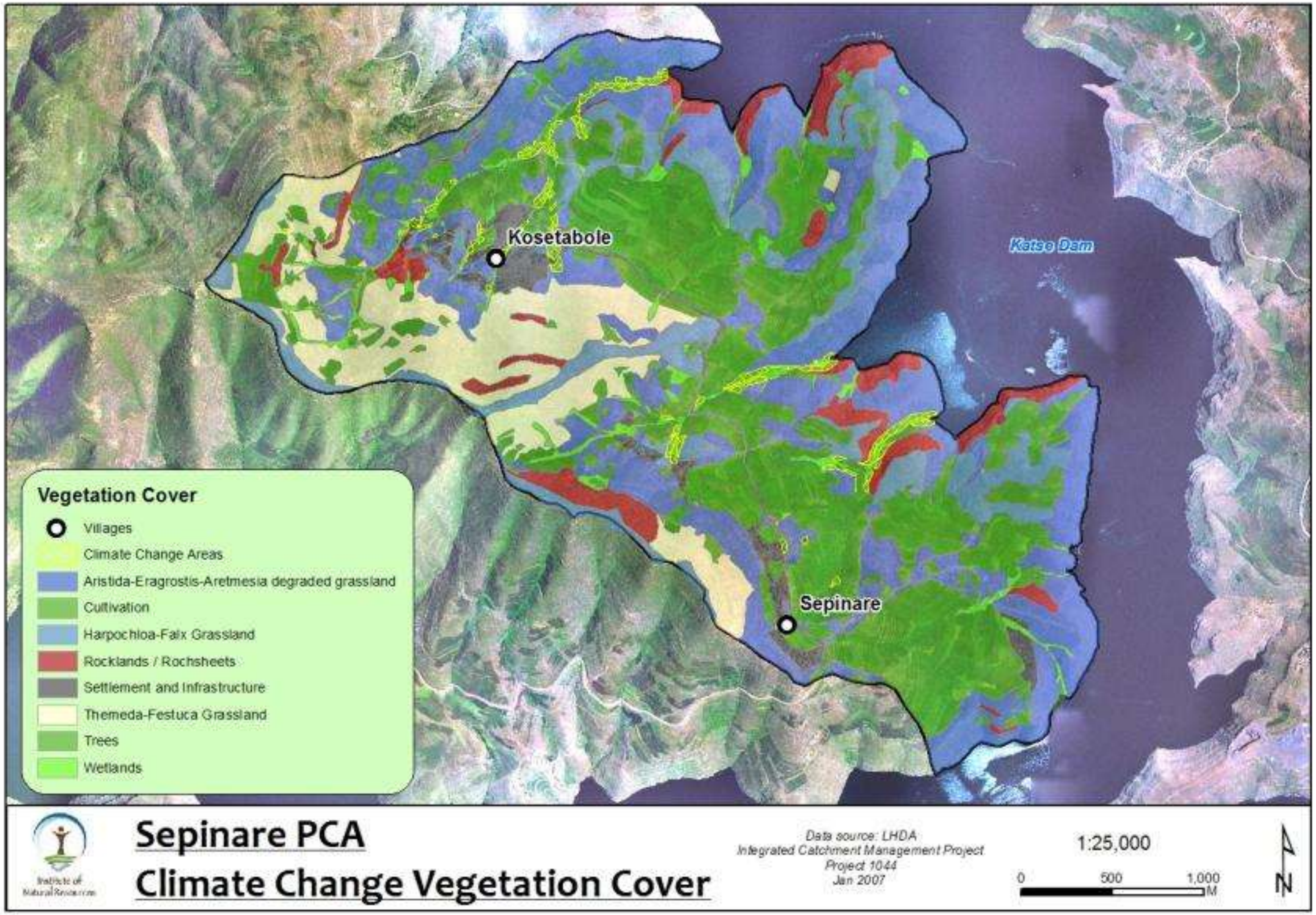
0 500 1,000 M
N


Kosetabole
Katse Dam
Sepinare
Vegetation Cover
Villages
Climate Change Areas
Aristida-Eragrostis-Aretmesia degraded grassland
Cultivation
Harpochloa-Falx Grassland
Rocklands / Rochsheets
Settlement and Infrastructure
Themeda-Festuca Grassland
Trees
Wetlands
Institute of Natural Resources
Sepinare PCA
Climate Change Vegetation Cover
Data source: LHDA
Integrated Catchment Management Project
Project 1044
Jan 2007
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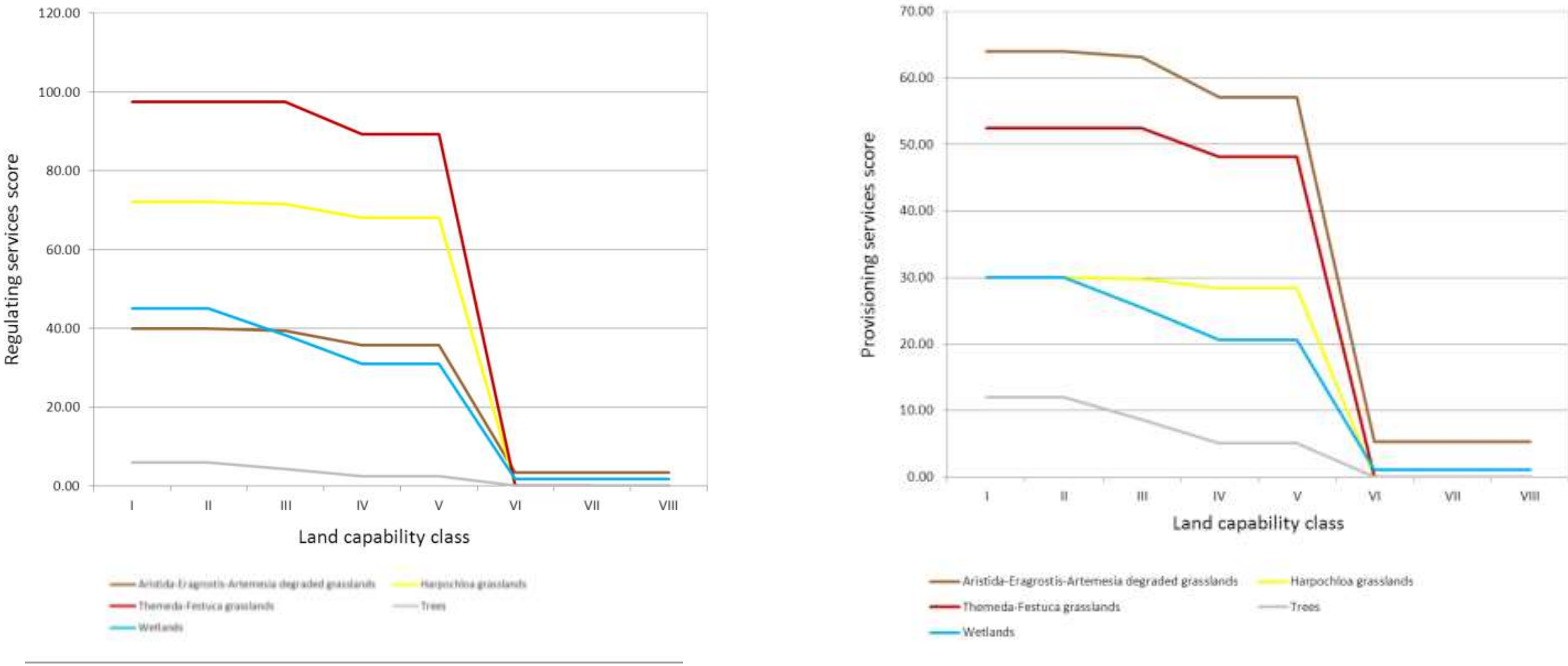
# Appendix E




**<u>Figure E1:</u>** Projected changes in provisioning services (left) and regulating and supporting services (right) at Sepinare for the Tortoise scenario

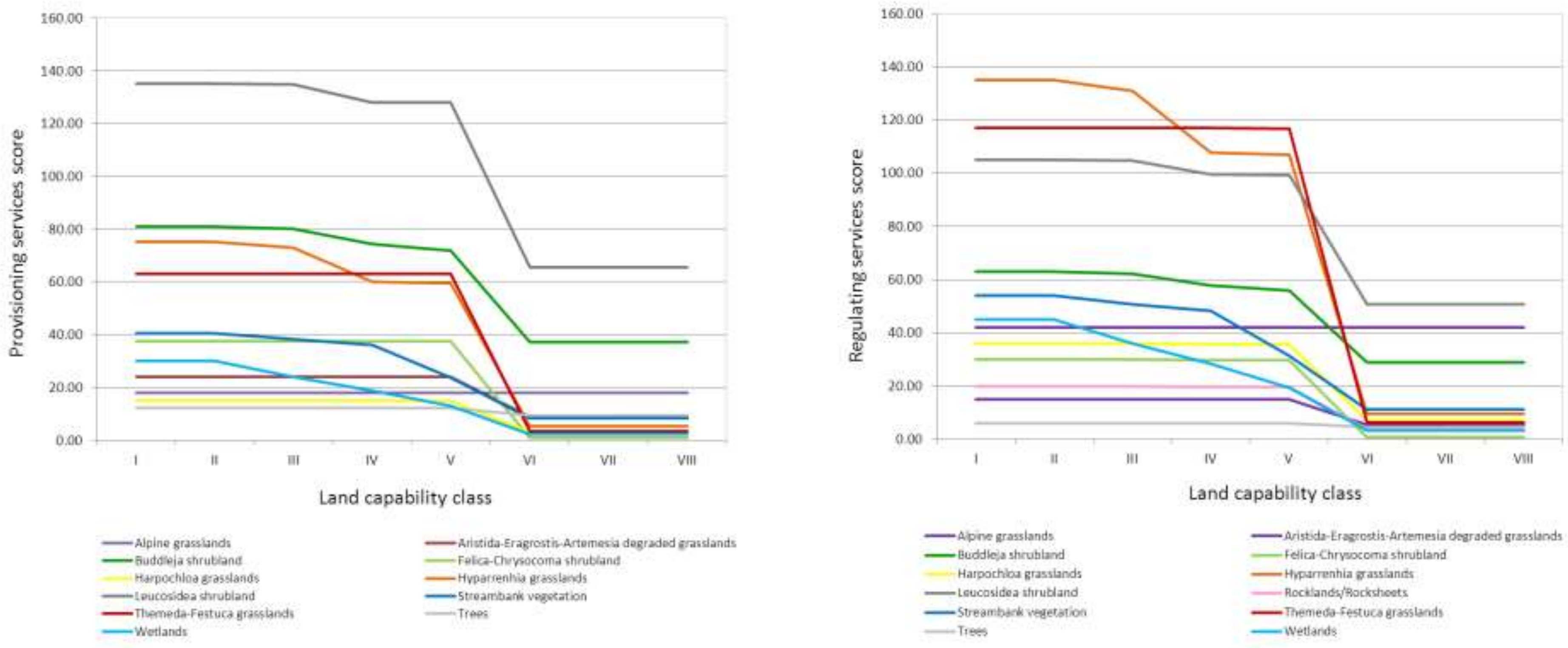
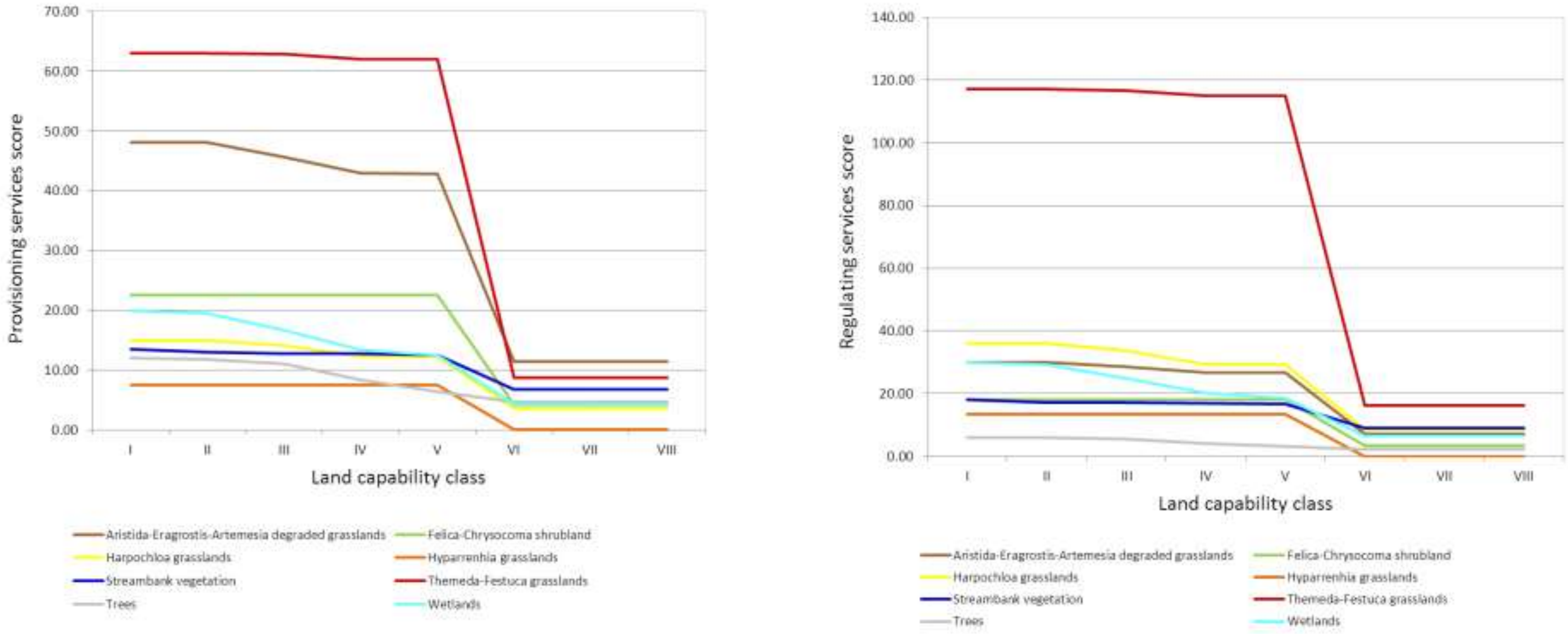
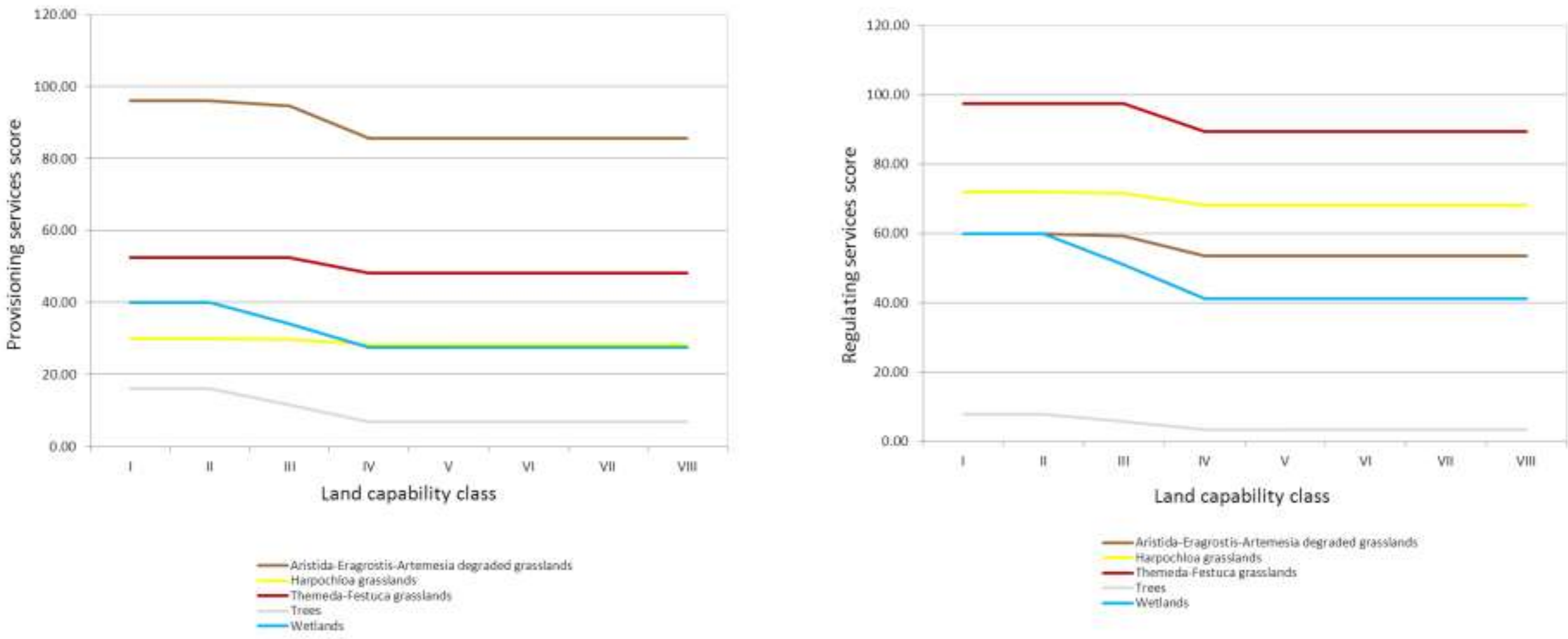


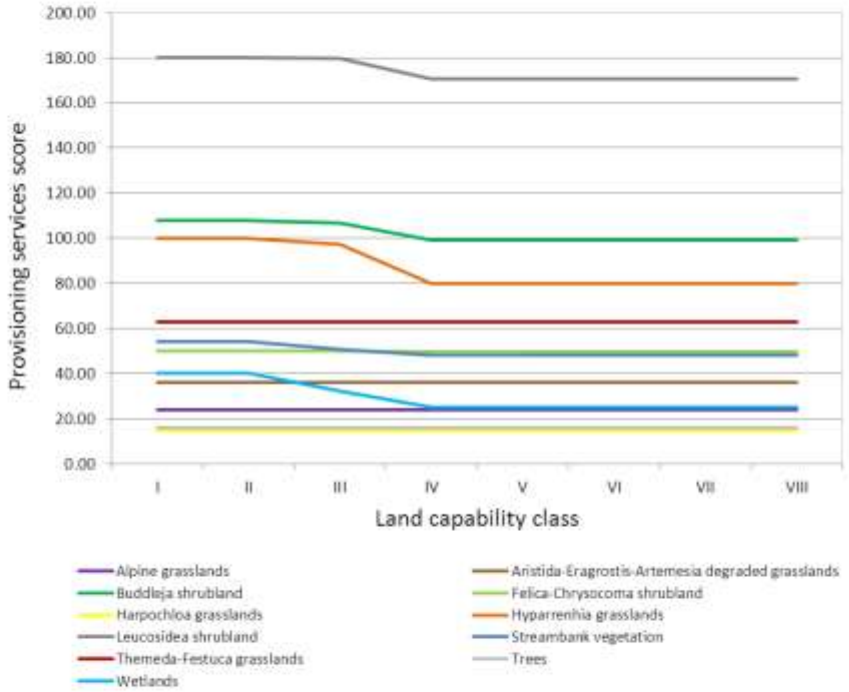

**Figure E2:** Projected changes in provisioning services (left) and regulating and supporting services (right) at Muela for the Tortoise scenario




**<u>Figure E3:</u>** Projected changes in provisioning services (left) and regulating and supporting services (right) at Setibi for the Tortoise scenario




**<u>Figure E4:</u>** Projected changes in provisioning services (left) and regulating and supporting services (right) at Sepinare for the Rabbit scenario



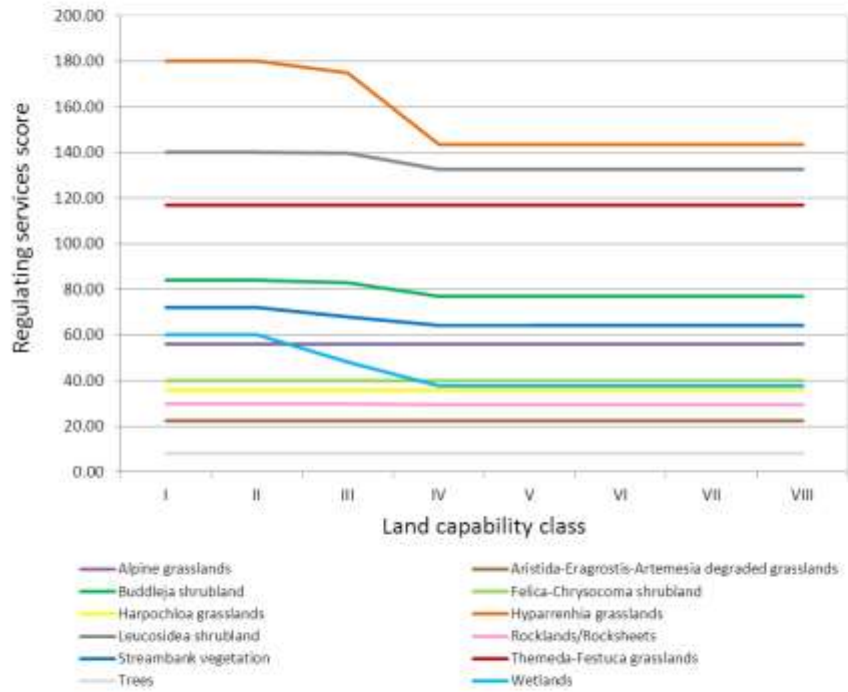
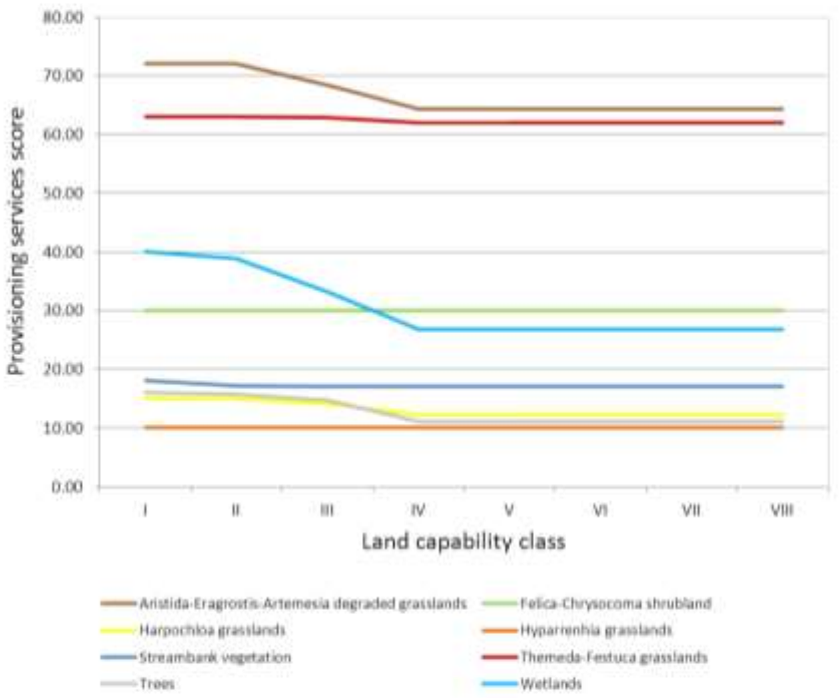




**Figure E5:** Projected changes in provisioning services (left) and regulating and supporting services (right) at Muela for the Rabbit scenario



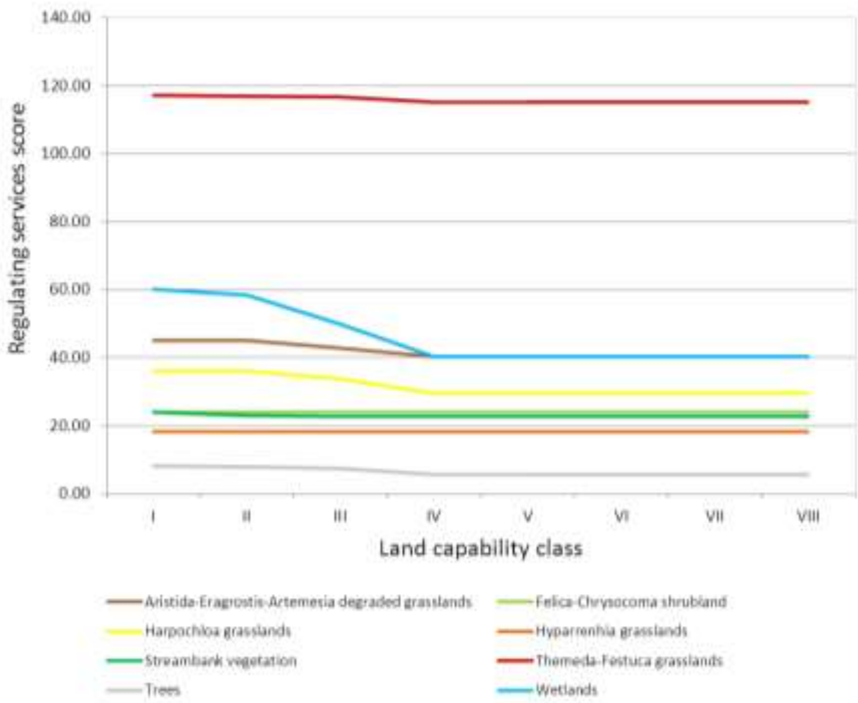
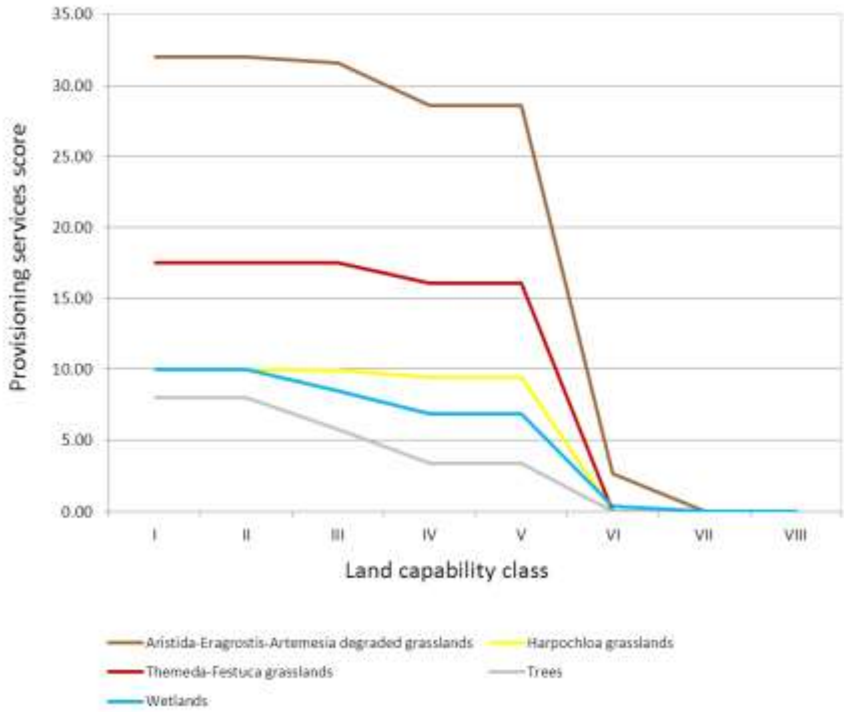




**Figure E6:** Projected changes in provisioning services (left) and regulating and supporting services (right) at Setibi for the Rabbit scenario



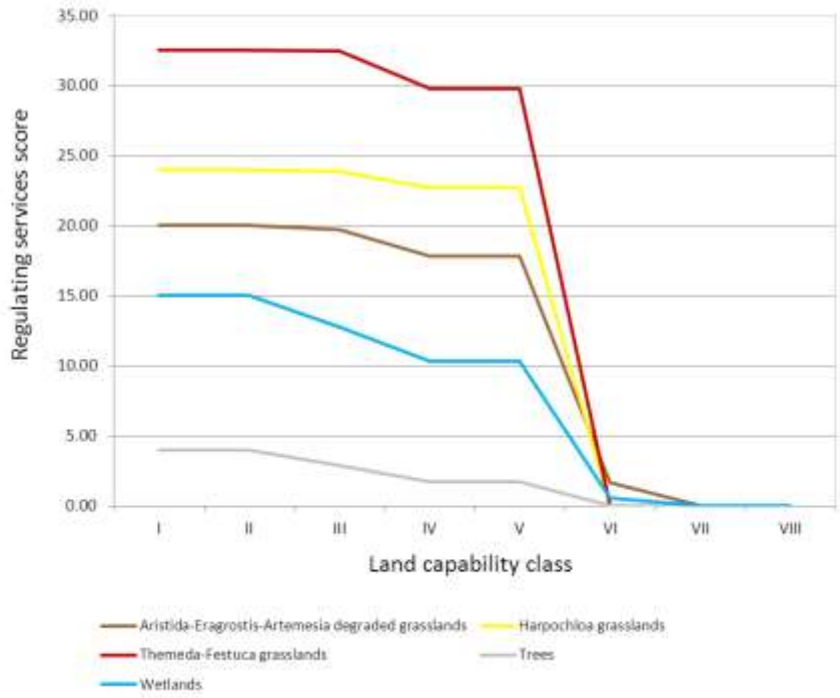




**Figure E7:** Projected changes in provisioning services (left) and regulating and supporting services (right) at Sepinare for the Vulture scenario

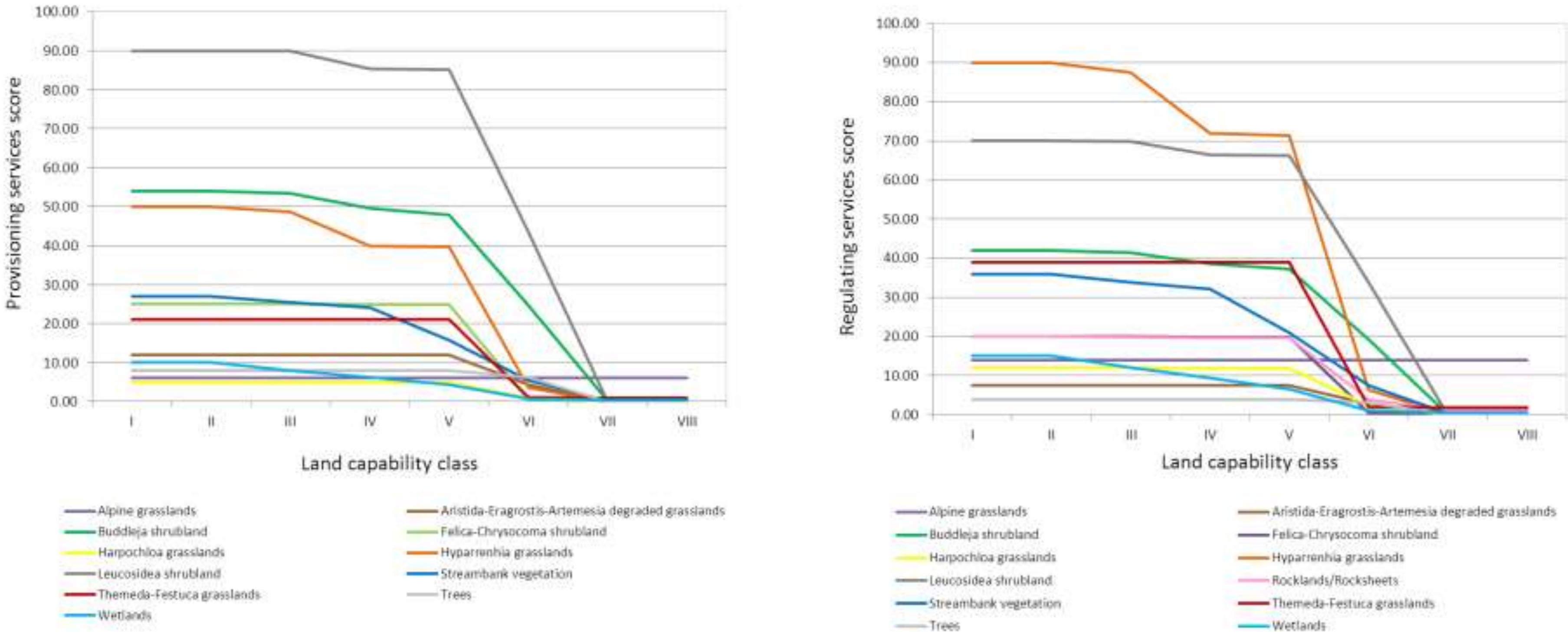



**Figure E8:** Projected changes in provisioning services (left) and regulating and supporting services (right) at Muela for the Vulture scenario

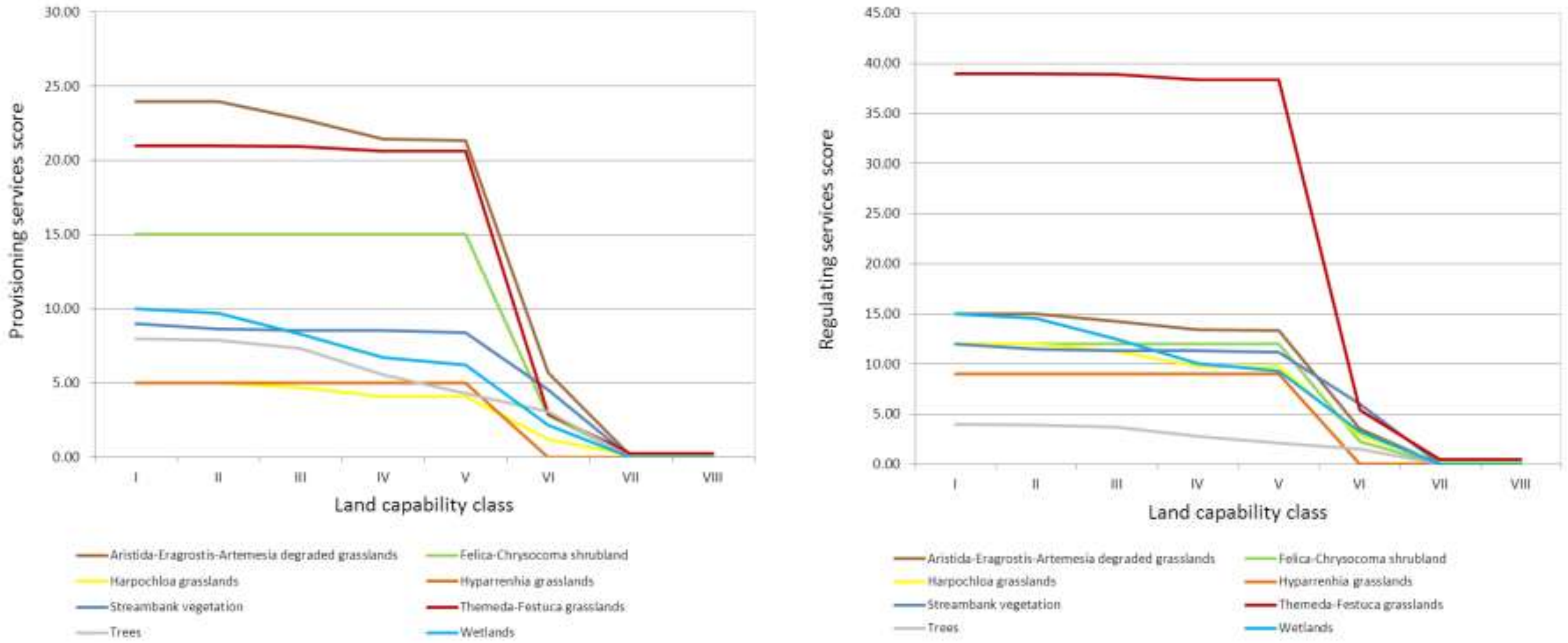
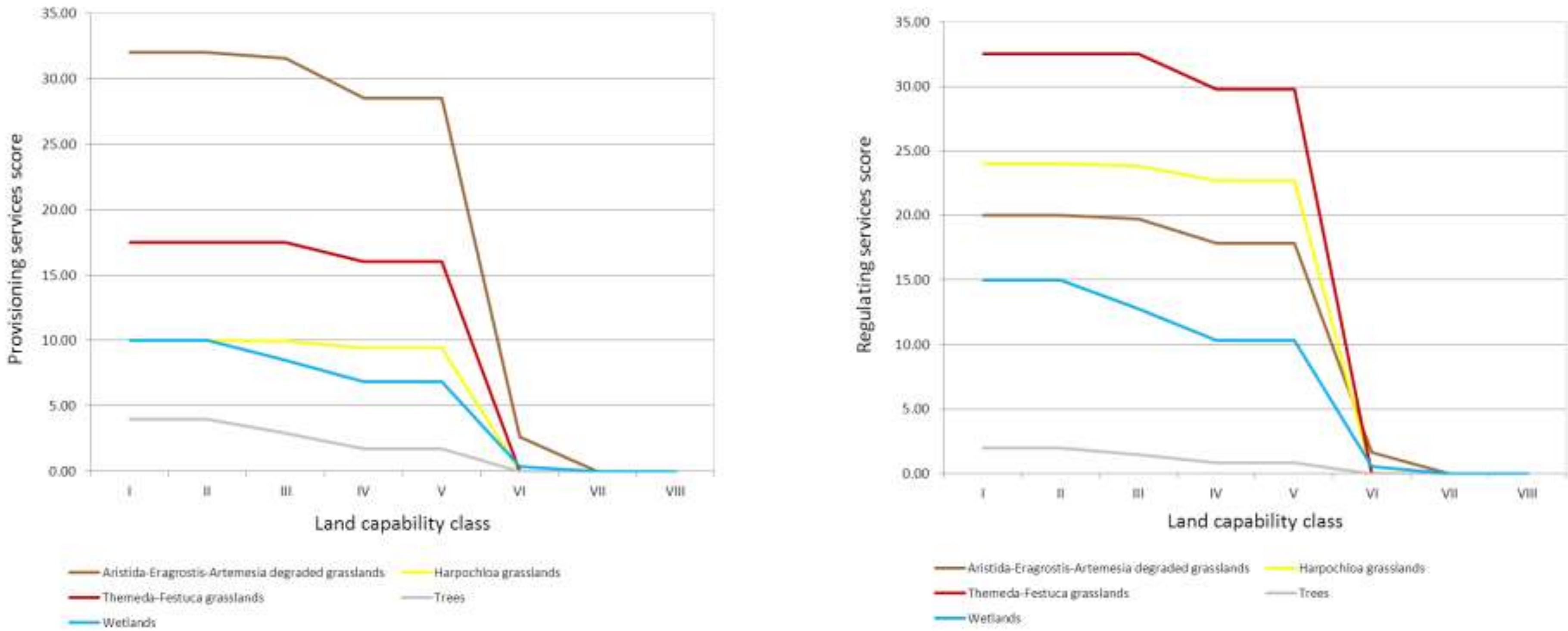
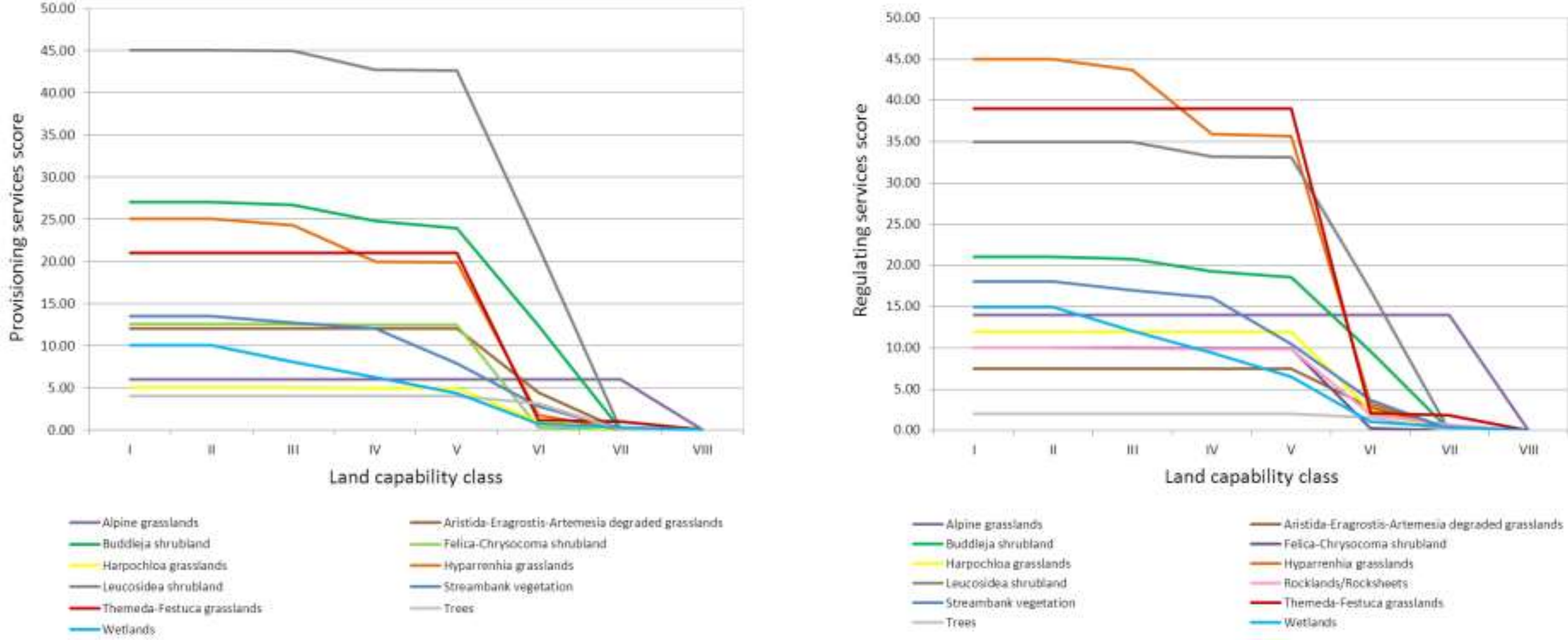



**Figure E9:** Projected changes in provisioning services (left) and regulating and supporting services (right) at Setibi for the Vulture scenario




**<u>Figure E10:</u>** Projected changes in provisioning services (left) and regulating and supporting services (right) at Sepinare for the Jackal scenario




**<u>Figure E11:</u>** Projected changes in provisioning services (left) and regulating and supporting services (right) at Muela for the Jackal scenario

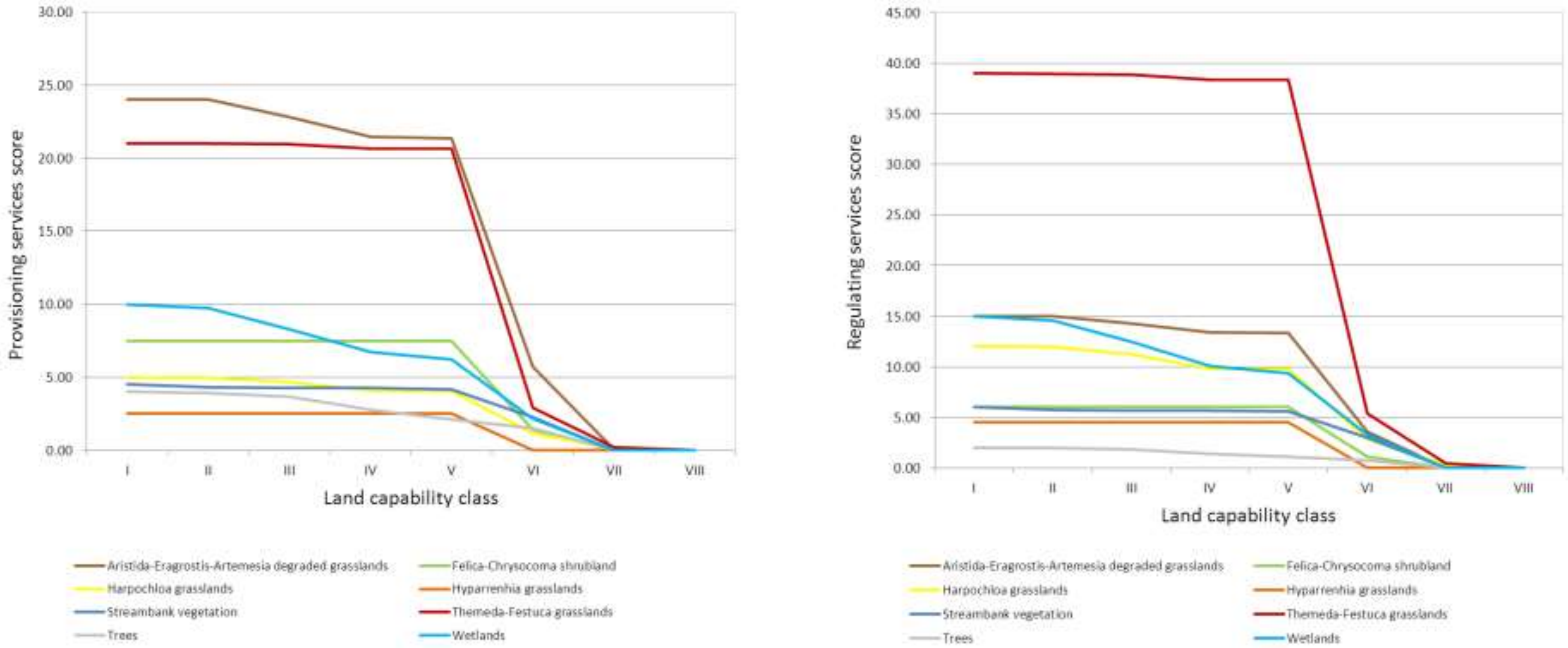



**Figure E12:** Projected changes in provisioning services (left) and regulating and supporting services (right) at Setibi for the Jackal scenario