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Centro de Estudos de Agricultura e Gestão de Recursos Naturais (CEAGRE)

IMPACT OF CLIMATE CHANGE ON MIOMBO WOODLANDS ECOSYSTEMS IN QUIRIMBAS NATIONAL PARK

(*Final Report*)

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LIST OF ACRONYMS

Acronym	Description
ANOVA	Analysis of Variance
CEAGRE	*Centro de Estudos em Agricultura e Gestão do Recursos Naturais*
CDZ	Community Development Zone
CVCA	Climate Vulnerability and Capacity Analysis
CV	Coefficient of variation
dbh	Diameter at Breast Height
DNTF	*Direcção Nacional de Terras e Florestas*
DPM	Disc Pasture Meter
GAI	Global Accuracy Index
GHG	Green House Gases
GIS	Geographic Information Systems
GPP	Gross Primary Production
GRNB	*Grupo de Gestão dos Recursos Naturais*
HDF	Hierarchical Data Format
INGC	*Instituto Nacional de Gestão de Calamidades*
IVI	Importance Value Index
JJA	June, July, August
LAI	Leaf Area Index
MAM	March, April, May
MODIS	Moderate Resolution Imaging

	Spectoradiometer
NPP	Net Primary production
QNP	Quirimbas National Park
REDD+	Reduced Emissions from Deforestation and Degradation
SE	Standard Error
SOC	Soil Organic Carbon
UEM	*Universidade Eduardo Mondlane*
USGS	United States Geological Service
UTM	Universal Transverse Mercator
WB	Woody Biomass
WWF	World Wide Fund for Nature

Executive summary

1. Introduction and objectives

The Miombo Ecoregion covers approximately 3.6 million km^2 in eleven countries of Central, Eastern and Southern Africa. The region is biologically rich and diverse both in terms of plant and animal species. In Mozambique the miombo woodlands occur to the North of the Save River up to the Rovuma River (i.e. the border with Tanzania) and occupy approximately two-thirds of the national forested area (Marzoli, 2007). It is highly important both ecologically and socio-economically as it provides goods and services for over 50% of the population.

The Quirimbas National Park (QNP) was created on June 6th, 2002 by the Council of Minister Decree N°14/2002. It is considered a global priority for biodiversity conservation due to the presence of miombo and coastal woodlands, spectacular granite outcroppings holding many endemic succulent plants, turtles, species-rich coral reefs, sea-grasses and mangrove ecosystems. Miombo woodlands comprise 40% of the park and supports the livelihoods of human populations. Ecologically, it is important due animal and plant species diversity. The woodlands in the park are facing several threats such as: illegal logging, fires, human and agricultural encroachment and climate change. These endanger miombo's ecology and its capacity to provide goods and services.

This study was conducted with the aim of understanding the effects of climate change on miombo woodlands and thus, to contribute to QNP's new management plan. The specific objectives of this task are: (1) Mapping and assess recent (22-year) trends in the extent of miombo cover; (2) Describing the status of miombo forests with respect to human disturbance; (3) Describing the status of wildlife resources in miombo forests with respect to human disturbance; (4) Identifying, analysing and evaluating observed changes in miombo forests and the ecosystem services they provide, and the possible or probable links to climate change trends and/or extreme events; (5) Identifying the main gaps in the state of knowledge of the impacts of climate change on miombo ecosystems, highlighting future research priorities; and (6) Identifying priority adaptation recommendations (policies or interventions) that would enhance resilience to climate change of miombo forests and related resources and livelihoods.

2. Study area description

The QNP is located in the northern coast of Mozambique, in Cabo Delgado Province, covering six districts: Meluco, Ancuabe, Macomia, Ibo, Pemba-Metuge and Quissanga. The tropical dry savanna climate is characteristic of the park, with an annual rainfall between 800 and 1200 mm. The miombo woodlands are characteristic of the ecoregion being dominated by *Brachystegia* spp. and *Julbernardia globiflora.* The diversity of ecosystems in the park represents important habitats for several fauna species, but there is still limited information about the diversity of animals. Human population is distributed across the 154 villages (102 in the core zone and 52 in the buffer area) located in 6 districts. The total population is estimated at 166.000 people, of which 57% live within the core area.

3. Methodology

In this assignment, we selected 5 villages (Namitil, Nanduli, Nguia, Napala and Miegane) according to the following criteria: accessibility; park zoning representativity and distribution; and presence of miombo. Around each village, we established two transects (one northwards and one southwards) and within each transect, three circular plots at 1 km, 3km and 5 km distances from the main village centre, for biodiversity assessment. In each plot we measured all trees (> 5 cm in Diameter at Breast Height-DBH) for dbh, height, tree species identification and grass biomass. Woody canopy cover and height were used as a proxy of habitat conditions and resources for mammals. The following ecological parameters were used to characterize the ecosystem: total and mean volume, total tree and grass biomass, dbh distribution, Importance Value Index, Shannon Diversity Index, Richness and Equitability Pielou index.

Landsat images for the years 1991, 1998, 2003, 2008 and 2013 were classified using a supervised classification in ERDAS 2014, to separate different land cover classes. Global Accuracy Index (GAI) and Kappa index (K) were used for accuracy assessment. We considered in this study the conversion of miombo areas to agriculture as degradation and mapped all those areas.

Freely available MODIS data (MOD14A1 and MCD45A1A) was used to characterize the fire regime in terms of: annual Density; fire extension; seasonality; frequency and intensity.

The socio economic approach to the communities was simplified from the CVCA (Climate Vulnerability and Capacity Analysis) methodology. A total of 9 discussion groups and 49 semi-structured interviews were conducted in the 5 selected villages. A Vulnerability Analysis Matrix was used to assess village's levels of vulnerability to climate change.

To address the impact of climate changes on the ecosystem, we used the Biome-BGC Version 4.10 (Biogeochemical Cycles) using climate prediction from the INGC for northern Mozambique (15% increase in precipitation and 3^{o}C increase in temperature, for the next 60 years). Global atmospheric carbon was also input in the model to predict changes in ecosystem's net primary production (as a proxy of biomass).

4. Results

Our results indicate that the miombo woodlands composed the biggest vegetation cover of the park area (38.9 %). Agriculture/settlement areas cover 4.6 % of park. Block A presented had the largest portion of miombo (59.15 %) and Block C had the lowest coverage (6.67 %). The global accuracy of the map can be considered very good (GAI=82% and K=78.83%). Land cover changes for the period 1991 - 2013 revealed that the open miombo did not change substantially in 22 years. There were substantial transitions from open miombo woodland to dense miombo woodland (3101 ha) and some loss of miombo to agriculture was observed (25% of loss). The fire regime between 2000 and 2014 showed an inter-annual cycle, an intra-annual variation associated with the rainfall distribution and an average frequency of 2-3 years (considered necessary to promote tree regeneration). However, at particular places (in the north and west) annual fires were observed, which may impose changes in the woodland. Fire regime may change in the next 40 years given the expected increase in temperature and precipitation for the region.

We identified 117 tree species distributed in 20 families (the dominant family being Fabaceae) and corresponding to an abundance of 309 trees/ha. The woodlands are represented by typical miombo tree species such as: *Julbernardia globiflora, Brachystegia boehmii, B. spiciformis, Diplorynchus condylocarpon* and *Pseudolachnostylis maprouneifolia*. These are common to the woodlands in the region. Blocks A and B were dominated by typical miombo species, while Block C showed elements of coastal forest such as the predominance of *Acacia* and *Albizia*. The Nguia village (located in the community development zone- CDZ) showed indications of human influence such as the ecological dominance of *Dichrostachys cinerea*. Block A and B had higher diversity of species (H'=3.45 and 3.20, respectively) and were richer in species (S=59 and 42, respectively) than Block C (H'=2.45; S=19) and CDZ (H'=2.26; S=27). The ecosystem is in general of medium to high stock with a total basal area of 156 m^2/ha and mean volume of 49.9 m^3/ha. Block A presents the highest stock in biomass with 44,9 Ton/ha, followed by Block B with 14 Ton/ha, CDZ with 9 Ton/ha and finally Block C had only 4 Ton/ha. The diametric distribution for Block A, B and C approximated the inversed J-shaped distribution indicating a stable stand. CDZ has an irregular diametric distribution, typical of a perturbed area.

The distance from the village analysis revealed that miombo tree species and forest resources (*J. globiflora, D. condylocarpon, M. stuhlmannii, B. boehmii*, etc.) were present at all distances. Diversity and richness were higher at 1 km (H'=3.78; S=68) from the villages followed by 3 km (H'=3.48 and S=50) and 5 km (H'=3.26 and S=58). Woody cover and height were lower at shorter distances from the villages. These results reveal that in the surrounding of settlements the woodland presented some kind of perturbation as expected. The woodland stock (volume and biomass) did not vary significantly among distances and the main timber species (*M. stuhlmanni, J. globiflora. P. angolensis, P. myrtifolia, B. boehmii* and *D. melanoxylon)* were well represented in all distances. The habitat for wildlife consisted predominantly of open to medium density woodlands, with close to 50% of woody canopy cover. In the proximities to villages (1km distance) the habitat was more open, where most plots have less than 25% of tree canopy cover. The number of mammal species was higher in shorter distances (1km). Common duiker (*Sylvicapra grimmia*) and impala (*Aepyceros melampus*) were more frequently found closer to settlements, whereas kudu (*Tragelaphus strepsiceros*) showed the opposite trend.

The biomass production in the last 60 years has decreased as a result of changes in precipitation, temperature and CO_2. For the next 40 years it is expected that a 15% increase in precipitation and 3^oC increase in temperature will cause a slight increase in biomass production. These may modify ecosystem diversity and structure and thus habitat for wildlife and availability of forest resources to local communities. The model was run with some imprecisions and thus the results have to be used with caution and monitored over time.

A total of 193 forest resources were cited in this study, the main being food and construction materials. The forest resources more consistently mentioned were mushroom and "minana" (tuber). Other included: beans, leaves, fruits and invertebrates; but construction materials (thatching grass and bamboo) and palm fibres for the production of mats and baskets were also commonly referred. Climate regulation and soil erosion control were also mentioned as ecosystem services from forests. In general, many food forest resources are only available during the rainy season (mushrooms and invertebrates mainly), but in general forest resources are ussed especially during the dry season when crop diversity is low. Ecosystem services scoring revealed that fruits were of low importance (although widely used), "other food" such as mushroom, tuber, leaves were very important, except for invertebrates, which were nearly all considered of low importance and fuel, construction and transformation material were rated as very important. The resources were in general accessible within 1hour walking distance (about 2 km) from the settlements. Resources collected further than 2 hours away are mostly classified as very important. Most resources are used for consumption, but construction and transformed materials are also for sale.

Climate changes have been felt in the last 20 years in the park and it was related to modifications in precipitation frequency and intensity. Napala community indicated drought problems, while all other communities suggested infrequent but very abundant rain. Excessive rains were associated with soil erosion and excessive accumulation of water in the crops, causing the roots to rot. Lack of rain was also mentioned as causing soil erosion, particularly associated to the effect of uncontrolled burning. People perceived that climate influences the seasonal availability of most forest products, although just a few trends through time have been noticed. Overexploitation of forest resources was referred as the main cause of ecosystem change and resources depletion. Napala presented the highest evidence of human pressure. In Miegane, conflicts with elephants were appointed as the cause for reduced availability of five different resources: bamboo (for construction), two fruits, one bean and one tuber (for food). Namitil indicated that forests are currently "further away" from the village than it was 10 years ago, the main reason being agriculture expansion. Napala community referred that uncontrolled burning and deforestation are causes of the reduction in thatching grass. Both gender in the family share the responsibility of agricultural activities and the collection of forest resources. The two groups have a common perception about the availability of resources. Women are also generally aware of conservation agriculture techniques. Most villages have diversified their activities and include commercialization in their livelihoods in the last 10 years. In Miegane a potential conflict with the *Taratibo* conservation area was identified. People state that it is an obstacle to livelihoods improvement since the local inhabitants are not involved in forest resources management.

All communities have benefited from economic and social development projects (Aga Khan, Helvetas and Kulima) such as agriculture and market access and they have some capacity to implement those activities. Napala community demonstrated interest organizing local associations for forest resources management. Nguia community did not show any kind of organizational initiatives. Vulnerability analysis revealed that the 5 communities are in general highly exposed to droughts, floods and storms, but Napala, Miegane and Nguia have the highest vulnerability given their respective location.

5. Conclusions

- The miombo woodlands occupy 38% of the QNP and have been relatively well maintained over the years.
- The woodland has considerable level of biodiversity and forest stocks (volume and biomass), but Blocks A and B are better stocked. These have potential for engaging in REDD+ projects.
- Local people rely deeply on the woodlands all year round, but especially during the dry season. The main woodland resources are: mushroom, wild fruits, honey and construction materials including thatch grass. Resources are mainly used for subsistence, but commercialization has become important in villages with better accessibility to roads and markets (Nguia and Napala).
- Fire frequency and intensity in the area are not particularly very high in the park and thus it might not be one of the major drivers of forest degradation in the area. However, areas of concern are the western and northern regions of the park.
- Changes in fire regime related to climate changes are expected and already observed in some portions of the park (Napala).
- Ecosystem primary production is expected to have a slight increase with changes in precipitation and temperature in the next 30-40 years. This trend must be carefully monitored over time since our predictions present some level of inaccuracy.
- Changes in primary production may change availability of forest resources to local people but also of habitat for wildlife, but this is also a matter of further follow up.
- Local communities have some level of organization and capacity to adapt to climate change. Conservation agriculture techniques are well spread, livelihood diversification was observed in Napala and Nguia, but it is related to better accessibility to roads and markets. There is, however, a need to capacitate

communities in forest management practices and engage them in tourism related activities.

6. Knowledge gaps

Our study indicates that the miombo woodlands in QNP may continue to be a carbon sink in the next 30-40 years, but the trend is still uncertain and needs to be further monitored. Additionally to climate change, land use and management systems may influence the ecosystem's capacity to store carbon. These are particularly important to understand given the current situation of the park (population growth, pressure over the forests) and in the context of developing strategies to mitigate the effects of climate change such as the REDD+ mechanism.

In this context, the identified knowledge gaps are: (i) below and under ground carbon stocks; (ii) fire regime (trends and emissions); (iii) payment for ecosystem services (economic valorization of forest resources); (iv) trends in species populations. Additionally the following gaps are important from the point of view of climate changes and its effect on miombo:

- No reliable predictions of change in climate variables at local spatial scale, where the impacts of climate change on biodiversity should be mitigated.
- Limited research and monitoring of key biodiversity components that would generate data and knowledge to support adaptive management decisions.
- Lack of long term data on seasonal movements and space use patterns by large mammals, to detect predicted changes in the distribution of species in the landscape.
- Difficulties in disentangling the impacts of climate change on miombo biodiversity from the impact of direct causes of biodiversity loss such as land cover change and overexploitation of natural resources.

8. Future research priorities

The following are future research priorities identified in this study:

- Long-term monitoring of the effects of climate changes in woodlands composition and structure, through the establishment of permanent sample plots and modeling.
- Assess the ecological condition and sustainable levels of collection for some ecosystem services: mushroom, wild fruits, honey and thatch grass.
- Determine the economic value of particular ecosystem services above referred.
- Assess the responses of particular species (timber, food, construction) to climate and human drivers.
- Study the link between climate and human drivers on ecosystems.

9. Policy-oriented Recommendations

Based on our results we recommend the following actions:

- Blocks A and B should be considered as pilot areas for developing REDD+ project. In developing REDD+ the identified knowledge gaps and research questions must be taken into consideration. Also, a detailed carbon inventory must be carried out beforehand.

- Support sustainable livelihoods in the protection zones, buffer zone and in the corridor, to reduce habitat conversion to cultivation, encroachment of human in wildlife key resource areas and the reduction of uncontrolled fires. This will help maintain habitat suitability in wildlife dispersal areas, which will be increasingly important to sustain wildlife populations under climate change in the wider Rovuma Landscape.
- Monitor changes in the distribution of density of large mammals in relation to natural (e.g. water distribution) and anthropogenic (e.g. human settlements and land cover change) factors through aerial surveys, as a basis for identifying priorities areas of the park for the allocation of management resources (including patrolling effort).
- It is urgent to define a global strategy for the QNP and resident communities to minimize the impact of climate phenomena and reinforce the local capacities to adapt to potential changes. This must engage local institutions (governmental and non-governmental) in the process of gathering data, analyzing climate risks and planning for appropriate actions, as well as establishing mechanisms for communication of climate information within the communities. Further training in climate-resilient agricultural practices and support for income diversification are priority areas to work with the communities in order to improve their resilience and adaptation to climate change.
- As opportunities for intervention, interviewees referred the donation of improved seeds, particularly of second-season ones (sweet potatoes and beans) and green vegetables, to ensure diet requirements in lean periods caused by floods or droughts; regular road maintenance and construction or rehabilitation of communal infrastructures, as schools, health centre and mosques.
- Building knowledge and skills on adaptation strategies specifically with women (eg. food preservation and valuation of local products), and promote the access to continuous education for the most vulnerable groups – women and children - is essential to increase individual capacity for adaptation, especially amongst most vulnerable groups in society.

1. Introduction

The Miombo Ecoregion covers approximately 3.6 million km^2 in eleven countries of Central, Eastern and Southern Africa. The region is biologically rich and diverse with around 4.590 plant species confined to this area, together with 35 endemic mammals, 51 endemic birds, 52 endemic reptiles, 25 endemic amphibians and an unknown number of endemic invertebrates. About half of the elephants (*Loxodonta africana*) and half of the rhinos (*Ceratotherium simum* and *Diceros bicornis*) left in Africa are found in this ecoregion.

Miombo woodlands in Mozambique occur mainly to the North of the Save River up to the Rovuma River (i.e. the border with Tanzania) and occupy approximately two-thirds of the national forested area (Marzoli, 2007). In many places miombo woodlands are subject to high levels of human pressure and are considered to be vulnerable to climate change impacts.

Climate change potentially poses a serious challenge to socio-economic development. Mozambique is considered to be relatively highly vulnerable to the impacts of climate change due to high level of exposure and limited adaptive capacity associated with poverty and dependency on the use of natural resources by a large share of the population. Climatic hazards such as droughts, erratic rainfall and floods are affecting human well-being. INGC (2009) predicts an increase in 15% of precipitation and 3^0C in temperature for northern Mozambique in the next 30-40 years, which may interfere with ecosystem productivity (given high evapotranspiration and flooding) and thus its capacity to provide goods and services to local communities.

The Quirimbas National Park (QNP) was created on June 6th, 2002 by the Council of Minister Decree N°14/2002. It is considered a global priority for biodiversity conservation due to the presence of miombo and coastal woodlands, spectacular granite outcroppings holding many endemic succulent plants, turtles, species-rich coral reefs, sea-grasses and mangrove ecosystems. The human factor within the QNP is complex: about 136.000 people in 102 villages reside permanently within the park boundaries and an additional 30.000 people (52 villages) live in the buffer zone. Twenty percent of the population is concentrated along the coast with the other people concentrated along the main roads that cross the park. As elsewhere in the province, education levels are low (illiteracy rates average 83%) and 95% of the economically active population works in smallholder agriculture on family-run farms, and in fisheries. Miombo forests within QNP are under illegal human pressure, particularly for timber, to build houses, and firewood to make charcoal. The demand for charcoal is from large urban centers (cities) (Management Plan QNP, 2013-2022).

In 2014 the Government of Mozambique has approved the new Management Plan (MP) for the Park for 2013-2022. The MP divides the park in 4 zones: (i) Total protection zone (46% of QNP's area); (ii) Specific use zone (13% of QNP's area); (iii) Community Development Zone (41% of QNP's area); and (iv) Buffer zone (10km around the park limits). For each zone there are three groups of activities: (a) regulated; (b) licensed activities and (c) non-permitted activities. This new orientation represents a challenge for park management and requires a detailed understanding of the current status of the ecosystem in terms of its capacity to maintain an ecological equilibrium and provide goods and services to local communities while at the same time fulfill the park's conservation objectives. Understanding the ecosystem implies the study of current and future, natural and anthropogenic, pressures to the ecosystem.

1.1. Objectives

The general objective of this study was to contribute to QNP's new management plan through:

1. Mapping and assess recent (22-year) trends in the extent of miombo cover;
2. Describing the status of miombo forests with respect to human disturbance;
3. Describing the status of wildlife resources in miombo forests with respect to human disturbance;
4. Identifying, analysing and evaluating observed changes in miombo forests and the ecosystem services they provide, and the possible or probable links to climate change trends and/or extreme events.
5. Identifying the main gaps in the state of knowledge of the impacts of climate change on miombo ecosystems, highlighting future research priorities.
6. Identifying priority adaptation recommendations (policies or interventions) that would enhance resilience to climate change of miombo forests and related resources and livelihoods.

2. Methodology

2.1 Study site description

2.1.1. Geographic location

The QNP is located in the northern coast of Mozambique, between the parallels 12^{o}0'00" and 12^{o}05'44" S and the longitude of 39^{o}10'00" and 40^{o}39'44"E, in Cabo Delgado Province, covering six districts: Meluco, Ancuabe, Macomia, Ibo, Pemba-Metuge and Quissanga (CEAGRE, 2010; QNP Management Plan 2013-2022; Figure 1). QNP covers an area of approximately 9.130km^2, of which about 87% is occupied by the terrestrial component and the remaining 13% are composed of island and marine habitats.

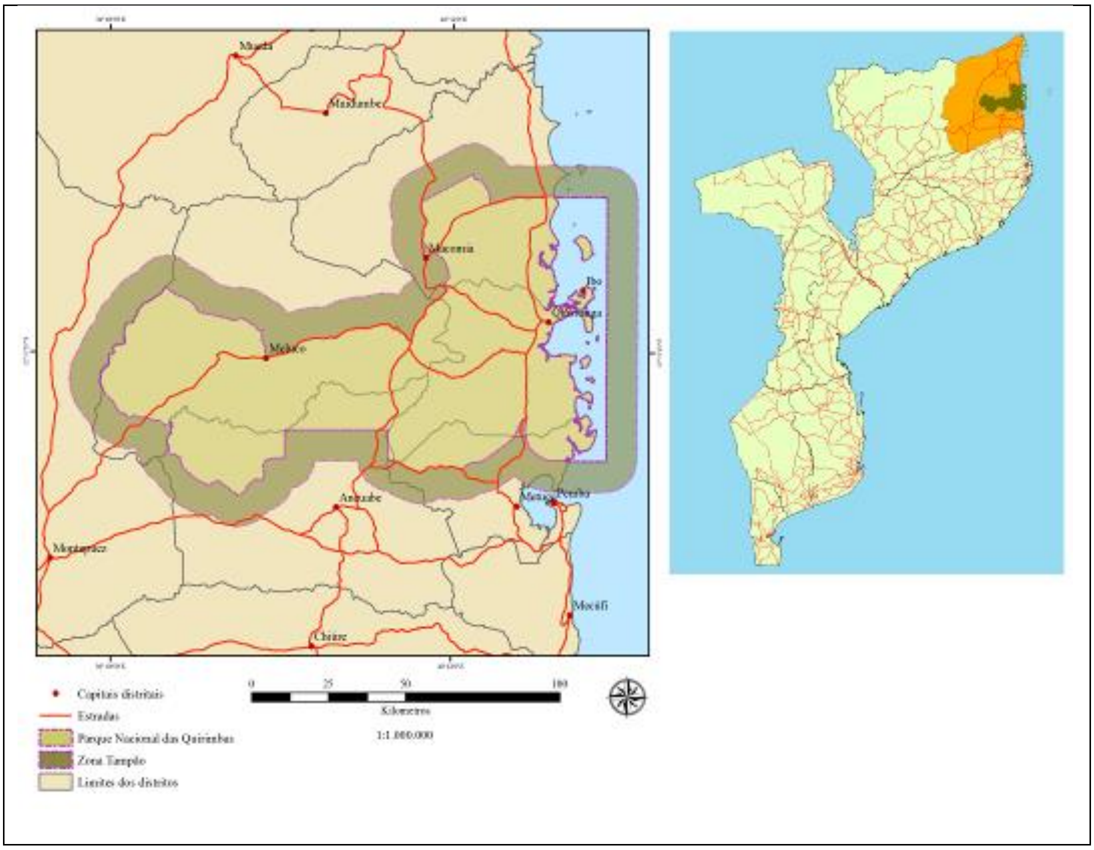

Figure 1. Location of Quirimbas National Park in northern Mozambique (Source: PNQ management plan, 2012).

2.1.2. Climate

According to Köppen's climate classification, QNP has a tropical dry savanna climate (Aw), with a dry sub-humid weather. The area has a pronounced dry season from April to October, with the driest month having precipitation of less than 60 mm. Rainfall is more abundant on the coast, decreasing steadily land inwards. The average annual rainfall ranges from 800 to 1200 mm. Most of the rainfall occurs in the period between November and March. High levels of precipitation (1000 mm to 1200 mm) occur in the coastal districts of Macomia and Quissanga. Continentality and altitude are the factors that most influence the spatial variation of rainfall across the park. Temperature values vary throughout the year between 20^o and 28^oC. However, temperature spatial distribution is almost uniform across the park. The coldest months are June and July, when the minimum average temperature can reach 15^o C. In contrast, the warmest months of the year are January and February, with temperatures reaching above 33^o C (FAO, 1995). According to the INGC (2009) this scenario is expected to change in the next 40-60 years with an estimated increase in temperature of 3^oC and 15% in annual precipitation.

2.1.3. Geomorphology and soils and hydrology

QNP is located in the gneiss-magmatic complex of the Mozambique 'belt', where *'inselbergs'* stand out on intrusive rocks of the Pre-Cambrian.

The altitude increases from the coast to the interior, the highest elevations being located towards the west, in Meluco district reaching up to 800 m. The highest peak is Mount Kuero. Lowlands make up a considerable part of the interior with altitude varying from 200 m to 500 m.

The park has an extensive river network consisting of four major rivers: Messalo, Montepuez, Muagamula and Muaguide. The largest lagoon is Bilibiza, which is located in Quissanga district near the coast.

The terrestrial inland area of the park is dominated by red soils of loam and brown clay soils. The western part is mostly occupied by red clay deep soils, which have an excellent capacity for water retention. These soils are classified as good to moderate soils for agriculture, generally with moderate drainage. In contrary, the river valleys are dominated by alluvial soils (Fluvisols), with dark and heavy texture, normally classified as medium to moderately good soils. These types of soils are often subject to regular flooding (FAO, 1995).

2.1.4. Terrestrial biodiversity

The QNP management plan (2013-2022) indicates that the park belongs to the phytogeographic region of the Inhambane-Zanzibar Coastal Mosaic, which is characterized by high flora diversity of more than 3.000 species, of which more than 100 are endemic (White, 1983). Burguess and Clark (2000) cited by Sitoe et al. (2010) refer that QNP is within the *swahelian regional endemism center*.

Bandeira et al. (2007) identified 6 vegetation types in the park, which follow an altitudinal gradient from the coast to the interior. In a sequential order, mangroves are followed by coastal thicket, Acacia-grassland mosaic, miombo woodlands, mixed woodlands, and miombo velloziace in the *inselbergs*. The miombo woodlands are by far the most extensive ecosystem in the area, covering 40% of the area.

The miombo woodlands are semi-deciduous during the whole dry season and dominated by *Brachystegia* spp. and *Julbernardia globiflora.* Variations in species composition do occur at the local level, being justified mainly by differences in moisture content. In humid lowland areas of the park the miombo is a dense woodland, trees reaching up to 20 m of height and more than 20 cm of diameter at breast height (dbh) (Bandeira et al., 2007). The grass stratum is dominated by grass, which can reach about 2 meters of height along valleys. The authors found a total of 59 tree species in this ecosystem and 5 of near or quasi-endemic species. The common trees species include: *Millettia stuhlmannii*, M. *bussei*, *Terminalia* spp., *Pteleopsis myrtifolia*, *Combretum* spp., *Dalbergia melanoxylon*, *Diplorhynchus condylocarpon, Afzelia quanzensis, Pterocarpus angolensis, Cordyla africana* among others. As the soil moisture content reduces towards the coast, the miombo woodlands tend to be less dense and poorer in terms of species composition. The grass stratum is much more abundant and dominated by grass species such as *Heteropogon contortus*, *Heteropogon melanocarpus, Urochloa mosambicensis, Digitaria eriantha,* among others. The valleys and depressions with alluvial soils are covered with *dambos* (grasslands) and palm velds. The *dambos* occur as seasonally flooded or inundated grassland areas in the park, dominated by *Typha* sp., *Cyperus* spp., *Phragmites australis* on darker inundated soils and *Hyphaene* sp., *Digitaria* sp., *Corchorus trilocularis*, etc. on the edges (Burguess *et al*., s/d, cited by Sitoe et al., 2010).

The diversity of ecosystems in the park represents important habitats for several fauna species, but there is still limited information about the diversity of animals. Several reports available at the QNP indicate that at least 46 species of mammals occur in the park (Bento, 2003; Schneider, 2004; Araman, 2007). The most abundant species include savanna baboon (*Papio cynocephalus ursinus)*, bushpig (*Potamochoerus larvatus*), warthog (*Phacochoerus aethiopicus*), kudu (*Tragelaphus strepsiceros*) and suni (*Neotragus moschatus*). According to DNTF (2009) the QNP is one of the five areas of the country with the highest diversity of medium-large mammals with highest concentrations in the interior of the Meluco, Quissanga, Macomia and Ancuabe districts. Four of the "*big five*" occur in the park. Rhinoceros (*Diceros bicornis* e *Cerathoterium simum*) occurrence has not been confirmed**.**

2.1.5. Threats to miombo woodlands

Several factors have been identified as imposing major threats to miombo woodlands within QNP, being the most important (GRNB, 2010): (i) exploitation of timber products (including logging); (ii) bushfires; (iii) human and agriculture encroachment; and (iv) climate change.

(i) Logging

There is no accurate information about the extent and dimension of logging in the park, but the reports indicate that logging for poles and plywood for commercialization and construction are important (Araman, 2006). Illegal logging is one of the main issues in the park and although no reports were found on this issue, our field observations and contacts with park authorities indicate that this topic may represent one of the main threats to miombo in the area, especially if considered that most timber species are found in these woodlands. According to Craig (2013) logging increased significantly between the 2011 and 2013.The park authorities have taken several measures to minimize the situation, which include: apprehension of timber stock, apply fine to transporters and loggers among others.

(ii) Bushfires

Bushfires have been appointed as one of the major threats to the ecosystems in the park, but we did not find specific information on fire occurrence and impacts in the area. However, during our field campaign fire was pointed out as an important tool for agriculture and hunting, but also as a threat to the ecosystem. Evidences from elsewhere in the eco-region indicate that although fire is an important factor for the ecology of miombo, changes in fire frequency and intensity may alter woodland composition and structure and thus the availability of forest resources to local communities.

(iii) Human and agriculture encroachment

Despite that slash and burn agriculture is a common practice in the park there is no data on the deforestation rate of intact vegetation, the types of vegetation affected, neither the estimate of the minimum time span for a soil to recover its fertility before it is used again for farming. Araman (2006) believes that major deforestation activities occur along access roads and around the main villages. This assertion is supported by field observations. The continuous deforestation of new intact areas due to population growth and urbanization may contribute significantly to the fragmentation of natural ecosystems in the park impacting negatively on the conservation of the overall biodiversity.

(iv) Climate change

There are no evidences of the effects of climate changes on miombo woodlands in the park, but there is an overall estimation of 15% reduction in precipitation for the miombo eco-regions (Chidumayo, 2001). On the other hand, the INGC (2009) indicates an increase in precipitation especially between January and May of about 15%. An exceeding increase in evapotranspiration however, caused by the expected $1^{o}C$ increase of temperature, will result in water deficit to vegetation. No drought or crop failure risks are expected for this zone but increased human pressure and conversion of forest cover to agriculture may occur. The INGC report estimates that seasonal variability in maximum temperature will decrease in the North region of the country, during the SON months and variability in minimum temperatures increases in the North during MAM and JJA months. Fire regimes are expected to change as a result of both climatic changes and associated increased human pressure. The INGC report estimates that the QNP will be at high to very high risk of fire occurrence, meaning that the ecosystems may experience compositional and structural modifications with implications for the availability of services.

An increase in precipitation may on the one hand contribute to increasing photosynthetic capacity resulting in higher biomass and carbon sequestration and consequently the availability of forest resources to local communities. On the other hand, high precipitation variability may change the water use efficiency of the woodlands thus reducing its capacity to thrive in changing climates. It may cause floods, damaging the woodlands. Also as the atmospheric CO_2 concentration increases trees can grow faster and saplings are more likely to be able to grow enough between fires to escape the flame zone (Bond, 2008).

2.1.6. Human Population

The population of the QNP is distributed across the 154 villages (102 in the core zone and 52 in the buffer area) located in 6 districts. The total population is estimated at 166.000 people, of which 57% live within the core area. The majority of the population is concentrated in the central QNP, along the coastline (mainly in the districts of Quissanga, Macomia and Pemba-Metuge) and along the main roads. There large human concentration in the main villages of Macomia, Quissanga and Meluco. Nevertheless, there are many areas with low population density, in which the natural habitats are still conserved (QNP management Plan 2013-2022). Craig (2013) mentions that 58% of the park is relatively free of permanent human influence and is shown to contain a wide diversity of habitats.

Almost 90% of the population is highly dependent on the exploitation of natural resources. Subsistence agriculture in small, un-irrigated family plots is practiced by 90% of the families, maize and cassava being the main crops. Cash crops in the area include peanut, rice, cassava, and maize. Livestock is anchored on the existence of small animals such as chicken, ducks, rabbits and goats. In general these animals are used for self-subsistence and to generate income in times of crisis (Mondlane Jr., 2010).

Communities' self-subsistence in the QNP is being topped up with the utilization of forest resources: wood (poles and plywood) and non-wooden products (wild fruits, honey, roots, mushrooms, tubers, medicinal plants and edible plants). Non-wooden forest products are used for consumption mainly in the dry period. Hunting is generally practiced for family subsistence, although in some occasions it becomes illegal if the hunted animals are sold (Mondlane Jr., 2010).

According to the QNP Management Plan (2013-2022) the exhausting of the resource base and the increase of poverty of the communities is the cause and consequence of the increased pressure over the existing natural resources of the QNP.

2.2. Site selection and sampling

As prescribed by the terms of reference of this assignment, we selected 5 villages distributed across the QNP and in agreement with WWF and park authorities (Table 1). Criteria for village selection were:

- Accessibility;
- Park zoning representativity and distribution; and
- Miombo woodlands occurrence.

Table 1. Villages selected for the miombo study.

Village	District	Park Zone
Nametil	Meluco	Block A
Miegane	Ancuabe	Block A
Nanduli	Quissanga	Block B
Nguia	Quissanga	Community Development Zone (CDZ)

Napala	Macomia	Block C

In each of these villages we conducted the socio-economic surveys described in section 2.2.4, which intended to address the relationships between people and the miombo ecosystem.

Biodiversity assessments were conducted around the villages in close collaboration with the socio-economic assessment for time and resources optimization. We established two transects (one northwards and one southwards) and within each transect, three circular plots were established at 1 km, 3km and 5 km distances from the main village centre. In total we established 6 circular (30-m in diameter-0.71 ha per plot) plots in each village, for a total of 30 plots for the entire area, i.e. a total sampling area of 2.1 ha. Within each plot we established two transects (in the north-south and east-west directions) for grass biomass assessments. Figure 2 indicates the sampling plots distribution in the study area.

The field work was conducted between the 9th and the 30th of March 2015.

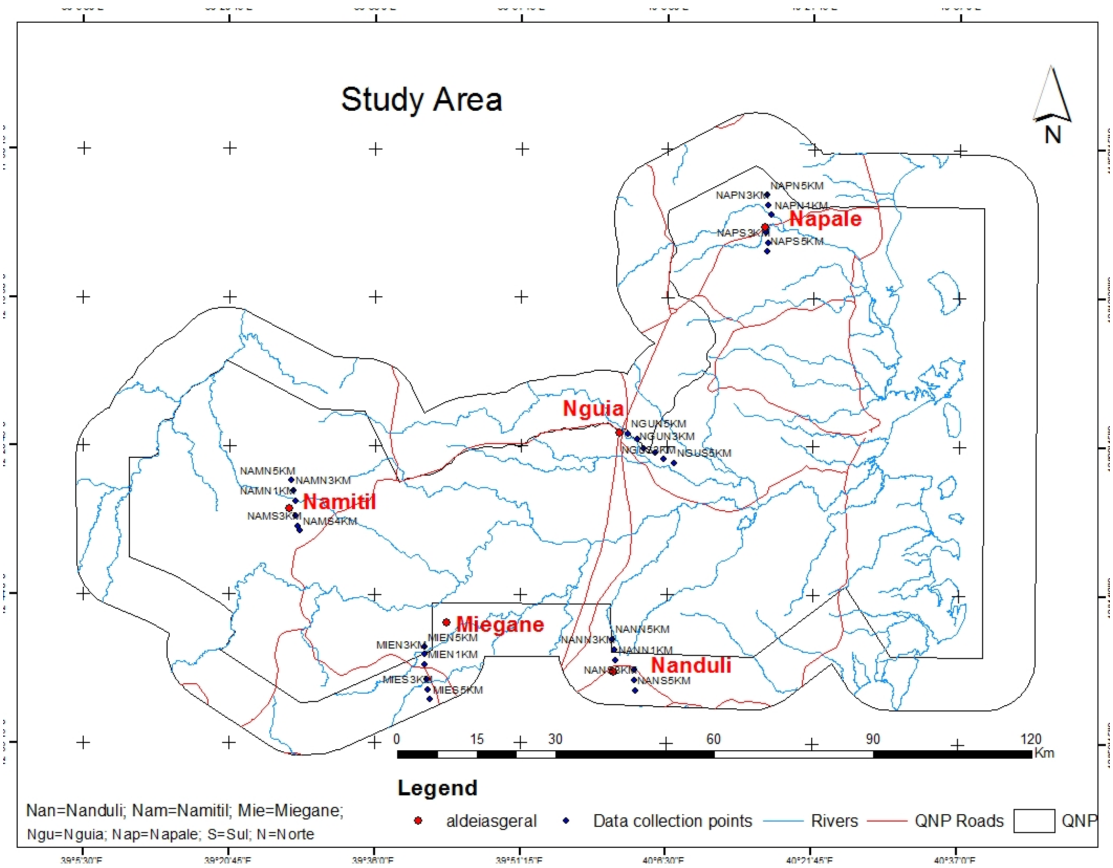

Figure 2. Distribution of sampling plots in the QNP.

2.3. Data acquisition and analysis

To achieve the objectives of this assignment, we used an integrated approach, which combines remote sensing and GIS techniques for land cover/land cover changes and degradation assessment, field methods for remote sensing validation and, biodiversity and ecosystem services assessments, socio-economic surveys to address human induced disturbances and assessment of main ecosystem services and modelling to address the impacts of climate change on the woodlands (Figure 3, is a schematic representation of the approach used).

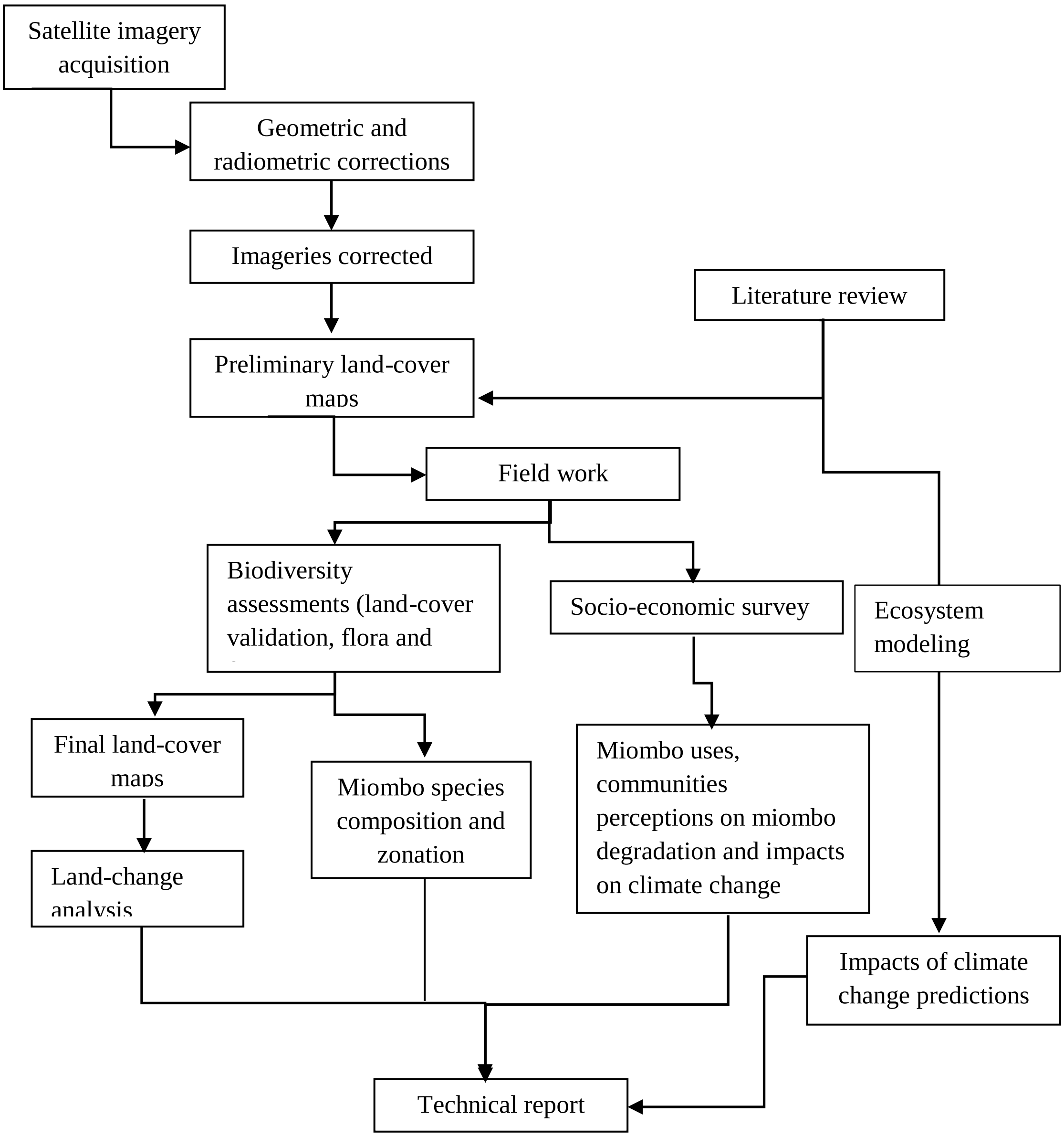

Figure 3. Summary of the methodology used in this study.

2.3.1. Land cover and degradation analysis

Satellite images from the Landsat Sensor freely obtained from the USGS website at www.glovis.usgs.gov, for the years 1991 (the 1993 images had a high percentage of clouds), 1998, 2003, 2008 and 2013. Four Landsat scenes in the path and row 164/65 and 168/69 cover the entire extension of the QNP, and thus 20 scenes were obtained for this study (Table 2).

Table 2. Landsat scenes covering the QNP and buffer zone.

Path – row number	Landsat Sensor	Period	Acquisition date	Cloud cover (%)
165 – 69	TM	1993	1991-05-06	0
165 – 69	TM	1998	1998-05-09	9
165 – 69	TM	2003	2004-05-09	0
165 – 69	TM	2008	2008-08-08	0
165 – 69	OLI_TIRS	2013	2013-06-03	0.21
165 – 68	TM	1993	1991-05-06	5
165 – 68	TM	1998	1998-05-25	3
165 – 68	TM	2003	2004-05-09	0
165 – 68	TM	2008	2007-05-02	0
165 – 68	OLI_TIRS	2013	2013-07-05	8.39
164 – 69	TM	1993	1991-08-19	0
164 – 69	TM	1998	1998-07-05	2
164 – 69	ETM+	2003	2003-04-22	0
164 – 69	TM	2008	2008-09-18	4
164 – 69	OLI_TIRS	2013	2013-07-14	8.33
164 – 68	TM	1993	1991-08-19	0
164 – 68	TM	1998	1999-09-18	9
164 – 68	TM	2003	2003-04-22	6
164 – 68	TM	2008	2008-09-02	0
164 – 68	OLI_TIRS	2013	2013-05-27	5.84

The images were initially pre-processed through geometric and radiometric corrections to avoid geographic and atmospheric distortions, using the existing algorithms in ERDAS IMAGINE 2014 and the parameters in the images metadata. Following these corrections, images from different years were co-registered to achieve better image-to-image comparisons.

All images were classified using an unsupervised classification to separate different land cover classes. In the next step, a supervised classification using the maximum likelihood algorithm in ERDAS IMAGINE 2014 was applied in order to obtain the final classification (Jensen, 2001). The classification scheme was based on the existing literature (Marzoli, 2007, Bandeira et al., 2007; QNP Management Plan 2012-2018) (Table 3), *Google Earth* Images and visual interpretations of the images. After the automatic classification, manual corrections were made. Fifty ground control points were selected among the miombo *vs* non-miombo classes for accuracy assessment purposes. Some of these points were visited and verified for class name, during the field trip. To improve accuracy, 50 additional ground control points were obtained from *Google Earth*. The accuracy assessment was carried out by using the

Global Accuracy Index (GAI) and Kappa index (K). The final land cover map for the year 2013 was produced at a 1:250 000 scale.

Table 3. Land cover classes used for the classification

Class nº	Class name
1	Open Miombo Woodland
2	Dense Miombo Woodland
3	Inselbergs/Miombo-Velloziace
4	Dense Mixed Woodland
5	Open Woodland/Grassland
6	Thickets
7	Mangroves
8	Agriculture/Settlements
9	Water

Based on the miombo spectral responses for the year 2013, the images from previous years (1991, 1998, 2003, 2008 and 2013) were also classified using the supervised classification algorithm of maximum likelihood. Land cover changes for 5 year-periods (1991-1998; 1998-2003; 2003-2008 and 2008-2013) were analysed using the image difference algorithm in ERDAS IMAGINE 2014. Areas of miombo cover changes during each period were calculated using the area calculation in Arcmap 10.

Mapping degradation with Landsat images is a very limited task given the medium resolution of the scenes (30-m) With this resolution it is not possible to measure forest degradation, which in general defined as the reduction of forest cover that affect the its capacity to provide goods and services (FAO, 2010). Thus a simple reduction in forest cover does not necessarily indicate forest degradation. To avoid committing this error, we considered in this study the conversion of miombo areas to agriculture as degradation and mapped all those areas.

2.3.2. Fire regime characterization

Give that fires have been referred as one of the main forest degradation factors in QNP, we characterized the fire regime for a period of 14 years (2000-2014) using the MODIS data, freely available on the internet at www.everb.echo.nasa.gov. Two MODIS products were obtained: the MODIS active fire (MOD14A1), which provides daily active fire information at 1km spatial resolution; and the MODIS burned area (MCD45A1A), which provides monthly data on area burned at a 500m spatial resolution. A combination of these two products allows for a comprehensive characterization of the fire regime by combining active fires and area burned. The MODIS products are all geometrically and radiometrically calibrated by the MODIS scientific team and thus pre-processing includes only: format conversion (from HDF to img), image projection from Sinusoidal projection to UTM, zone 37S, datum WGS84 and study area extraction.

The fire regime in this study was characterized using the following parameters:

(i) **Annual Fire Density (Number of fires/km^2):** provides information about the spatial distribution of fire in the area revealing the places that had more fires in a year.

(ii) **Extension of burn (km^2):** indicates the amount of area burned in a year for the entire park.

(iii) **Seasonality**: indicates season of the year in which the park has more area burned. For this purpose a year was divided in three periods to reflect the climatic seasons (November-January- beginning of the wet season, February-April, peak of the wet season and May-October- the dry season).

(iv) **Fire Frequency:** represents the number of times a particular place in the area burns during the period of analysis (14 years). This parameter is of particular importance in addressing the impacts of fires on vegetation.

(v) **Fire Intensity (Kj^{-1}):** indicates the strength of the fire that can impact the ecosystem.

All parameters are directly related to climate change as modifications in temperature and precipitation may alter the fire regime and thus its impacts on the ecosystem.

Fire analysis was performed in Arcmap 10 and ERDAS IMAGINE 2014 using different algorithms. Fire density was calculated by adding the daily active fires for a year and then using the density calculator procedure; Extent of burn was calculated by extracting the burned pixels (pixel number between 1-365) and then using the area calculator procedure; fire frequency was assessed by adding the monthly data for a year and then adding the 14 years to identify those pixels that burned several times during the period; Fire intensity was extracted directly from the attribute table in the active fire product. The analyses were performed for annual, seasonal (dry and wet seasons) and monthly periods of the years.

2.3.3. Biodiversity assessments

Biodiversity assessments intended to describe the current status of the ecosystem and of the main provisional ecosystem services to local communities.

<u>Tree surveys</u>

Within each plot we measured all trees equal or greater that 5 cm in Diameter at Breast Height (dbh), height (m) and identified the species. Specimens were collected in the field and sent to the Herbarium at the Department of Biological Sciences from Eduardo Mondlane University (UEM) for botanical identification. Within each plot and transect we observed and recorded any sign of degradation/damage to the trees and ecosystem.

Grass Surveys

Biomass of the grass was estimated with a Disc Pasture Meter (DPM; Figure 4) developed by Bransby and Tainton (1977) for the African savannas, using 60 disc meter readings recorded at 1-meter intervals along the 2 transects (30 readings/transect). The DPM measures the height (cm) of the fallen disc in the grass sward, which is directly related to its biomass. Using the allometric equation below, calibrated by Trollope & Potgieter (1986), and that can be used as a general calibration for estimating grass fuel loads for grasslands and savannas in southern and east Africa regions (Trollope *et. al*. 2000), the height is converted to biomass (kg/m^2).

$$Y = -3019 + 2260\sqrt{x}$$

Where: Y=fuel load (kg/ha); x=DPM reading (cm).

Figure 4: The Disc Pasture Meter (DPM) used for estimating grass fuel loads in the sample plots.

Fauna surveys

Fauna surveys focused on mammals because this class is the main source of animal protein obtained from natural ecosystems by local communities. We established two transects in each village, one northward and one southward. Two circular plots of 15 m radius each, spaced by 300 m were established at 1 km, 3km and 5km from the centre of the village. In total we established 12 circular plots in each village (four for each distance from the village). We collected data on mammal occurrence by direct observation and identification of mammals using field guides (e.g. Stuart & Stuart, 2001). Distance sampling technique (Buckland *et al*. 2001) was applied in data collection, recording the distance and the angle of each animal sight in relation to the line transect. However, most mammals were difficult to observe directly during ground surveys either because they flee in response to the approaching observer or because they are nocturnal. Additionally, wildlife population sizes are small in the QNP (Craig 2013). As a consequence, the number of sightings was very low (<5 sightings/transect) for a meaningful estimate of animal density using distance sampling technique (Buckland *et al*. 2001). Therefore, indirect methods were the main method used to detect the presence of mammal species. Accordingly, along the transect and within the plots, animal signs such as footprints, droppings, feedings signs and diggings/burrows were sought and identified following Walker (1996). Evidences of hunting or trapping of animals by local people were also recorded.

To assess habitat conditions and resources, we estimated woody canopy cover as the proportion of the foraging area shaded or covered by trees (height ≥2.5m) or shrubs (height <2.5m), using the procedure outlined by Walker (1976). The percentage cover was grouped into the following classes: 0; 1-10; 11-25; 26-50; 51-75. The height of the top canopy cover was estimated and grouped into the following height categories: short trees (height ≤5 m); medium trees (6-10 m) and tall trees (>10 m). Tree cover indicates the potential of the habitat to provide shade and shelter for the animals and to retain the more nutritious grass leaves during the dry season. Shrub cover is an indirect measure of horizontal visibility and of the potential predation risk associated with ambush predators, such as lions (*Panthera leo*).

<u>Data analysis</u>

The analysis were performed to achieve a detailed ecological characterization of the ecosystem per park zone and to detect variations according to the proximity to the villages as a proxy of disturbance levels.

Analysis of variance (ANOVA) at 1% level of significance was performed to analyze the differences between distances from the villages (1km, 3km and 5km) for the grass biomass and woody (volume, biomass, dbh and height) response variables. These analyses were all performed on the StatsPlus package. Biomass was calculated using an alometric equation (formulae below) developed by Chamshama et al. (2004) for the miombo woodlands in Tanzania.

$$WB = b1 \times (dbh)^{b0}$$

Where WB= woody biomass (kg per tree); b1=2.553; b0-0.0625; dbh=Diameter at the Breast Height.

The Importance Value Index (Kent, 2012) was determined for woody vegetation as per the formulae below.

Importance Value Index = Relative density + Relative dominance + Relative Frequency

The Shannon Diversity Index (H’) was performed using the formulae:

$$H' = -\sum_{i=1}^{n} piLn(pi)$$

Where: H’= Shannon Index; pi= proportion of individuals belonging to the ith species.

Richness (S) was measured as the number of species and the equitability Pielou Index (J’) was calculated using the formulae:

$$J' = H'/\ln S$$

For the analysis of fauna data, we amalgamated data collected within the same distance from the village (1km, 3km and 5km) regardless of the village, to increase sample size and the robustness of the analysis. To assess the distribution of mammal species, we calculated the frequency of occurrence as the proportion of plots where each mammal species was recorded from the total plots surveyed within each distance from the village. We computed binomial confidence intervals for proportions to compare species presence in plots located in different distance from the villages. The relative availability of mammal species within each distance from the village was assessed by dividing the number of sighting of each species by the total sighting of all species within each distance from the village. Changes in the prevailing habitat conditions and resources were also assessed by comparing proportions of each category of habitat variables among distances from village.

2.3.4. Socio-economic surveys

We used socio economic approach adapted (simplified) from the CVCA (Climate Vulnerability and Capacity Analysis) methodology, which provides a framework for analyzing vulnerability and capacity to adapt to climate change at the community level (Care, 2009). It used a combination of methods, and was designed to maximize information gathering, considering time constraints and any potential lack of cooperation within the field. It also aimed to corroborate information from different sources, as most questions were approached in both strategies (Kanbur et al. 2001).

The communities’ general context and characteristics, namely demography, accessibility to main roads, main economic activities and general adaptive capacity towards climate change were assessed using a semi-structured interview directed to the community leader (Annex I). The main forest resources used, the perception on climate change and adaptation measures being used by people were assessed both in discussion groups, conducted separately with man and women, and individual semi-structured interviews, also targeting resident man and women. Participants for the discussion groups and individual interviews were in most cases designated by the community leader or, otherwise, based on their availability at the time of the fieldwork. Each person participated in only one of the sampling strategies, either in a group or individually, to maximize sampling effort within each community.

A total of 9 discussion groups were conducted in the five communities, as in Nguia it was impossible to organize the women's group. This was due to the unavailability of women to participate as a group during the time the team was in the community (Table 4). Annex I presents the guiding questions for the focus groups. Discussion groups have taken between 54mins and 1h53mins, i.e. an average duration of 1h36mins. The discussion groups were conducted with 5 to 7 participants, the number determined to optimize communication, as translation was needed in most cases. The discussions were conducted isolated from other residents. The first exercise conducted was registered on a flipchart and aimed at the identification of forest resources used and their general availability and importance. It included resource listing, necessary time to collect each resource, its seasonality and availability, and scoring exercises for their importance and difficulty to collect. Afterwards, a discussion was conducted on the group's perception on climate change and risks, the potential impact of climate risks on listed forest resources, the impact of climate risks on livelihoods and actual measures taken to adapt community life to climate hazards. Open questions were used to guide this discussion. Data collection finalized with suggestions and/or recommendations from participants on how to improve adaptive capacity of the community, with or without support from external sources.

Table 4. socioeconomic data collection methods and sample sizes

Community	Sampling dates	Discussion group – men (number participants)	Discussion group – women (number participants)	Individual interviews – men (number interviewees)	Individual interviews – women (number interviewees)
Namitil	11/3 and 12/3	6	7	5	5
Nanduli	13/3 and 14/3	5	5	5	5
Napala	15/3 and 16/3	6	7	5	5
Nguia	17/3 and 18/3	6	0	5	5
Miegane	19/3 and 20/3	5	5	4	5
	TOTAL	**28**	**24**	**24**	**25**

We applied 49 interviews (out of 50 aimed) with only one male participant missing in Miegane. This was due to the unavailability of the man at the time in the field to implement the last interview. Interviews lasted for 28mins to 46mins, i.e. an average duration of 33mins. The information targeted by the interviews was quite similar to the discussion groups, plus the socio-economic contextualization of the household relating resource use. It assessed the household size, composition and origin (if migrant); the economic activities conducted by household members and their contribution to their subsistence; the description of agricultural production and observed changes; the listing of forest resources used within the household, its commercial value, seasonality, effort to collect them (measured in the average time to harvest in a return walk and categorized between 1 and 4), and their and importance in family life (classified from 1 – not so important, to 3 – very important); people's perceptions of climate change and the impact of climate events on household livelihoods and individual measures taken to adapt to climate risks. Semi-structured interviews ended with suggestions and/or recommendations on how to improve adaptive capacity of the community, with or without support from external sources (Annex II).

The analysis presented in this report is mainly based on data from semi-structured interviews, but results were in all cases corroborated by the ones observed for discussion groups. Exploratory analysis of both responses using software Excel® and SPSS® permits a general examination of forest resource use in the PNQ to subsequently analyze its role in the scope of communities' vulnerability to climate change.

2.3.5. Vulnerability analysis

Based on the land cover, fire, biodiversity and socio-economic analysis we performed a vulnerability analysis using a Vulnerability Analysis Matrix proposed by ActionAid (s/d) and ACF (2012). The matrix includes climate-related risk identification, exposure of local communities to risks, action taken to overcome the risks and finally the capacity of the communities to overcome environmental hazards and to adapt to climate change.

2.3.6. Ecosystem modelling

To address the impact of climate changes on the ecosystem, we used the Biome-BGC Version 4.10 (Biogeochemical Cycles) developed by Thornton and Running (2002, 2010), which is a mechanistic model that was originally developed in 1999 at the Numerical Terra Dynamics Simulation Group at the University of Montana, USA. The model is designed to use daily climate data and site conditions (elevation, slope) to estimate Net Primary Production (NPP) for the ecosystem (Hong-Xin and Wei-Guo, 2004). NPP represents the net accumulation of C by the stand and is determined as the difference between Gross Primary Production (GPP) and the sum of the maintenance (Rm) and growth respiration (Rg) components. Therefore, Biome-BGC captures effects of a number of abiotic (temperature, vapour pressure deficit, soil water, solar radiation, and CO_2 concentration) and biotic parameters (leaf area index, leaf, and root N contents) that controls on NPP.

The model requires ecophysiology and climatic parameterization using ecosystem specific variables. Biome–BGC uses a daily time step in order to take advantage of widely available daily temperature and precipitation data from which daylight averages of short wave radiation, vapour pressure deficit, and temperature are estimated (White, 2000). In this study, the daily climate data were adjusted for the site conditions (for example slope, aspect, albedo, elevation, precipitation pattern) using a microclimate simulation model, MT-CLIM (Running et al., 1987; Glassy and Running, 1994). Current climate data for the study area were simulated by MT–CLIM based on the data from 1952 to 2015 recorded at the Mozambique National Institute of Meteorology. The data for 1972 to 1974 and 2004 were incomplete, and were removed from the dataset. The ecophysiological parameters used for the model initialization were collected from several sources in the miombo ecoregion given the fact that these parameters do not exist for the QNP region. Annex III presents the details of the parameters used in the BIOME-BGC model for this study.

We considered 60 years of simulation between 1952-2015 using daily temperature and precipitation data. Likewise projections were made for a period of 45 years in order to evaluate the trends in NPP, LAI and CO_2. In this case, the projection was made through extrapolation of temperature and precipitation data for the period between 2015 to 2035 (20 years) and 2015 to 2040 (25 years) obtained from the projections made by the INGC (2009) for northern Mozambique over a period of 60 years, which indicates a 15% increase in precipitation and 3^{o}C increase in temperature.

2.4. Study Limitations

This study had several constraints, which in a way have limited the full achievement of proposed objectives. The main limitation was the short period allocated to the study – 4 months – which hindered the detailed consideration of the effects of climate change on the woodlands. The field campaign of only 15 days (2 days per village) was too short to achieve a full characterization of the ecosystem and application of participatory methods. Additionally the fieldwork was carried out during the peak of the wet season (March), which imposed further constraints on data collection, including map validation. In addition to time constraints, there is very limited information and data about climatic variables, which were crucial to address the impacts on the woodlands. As a consequence, the analysis of future scenarios was carried out based on the only literature available, the INGC (2009) summary report. Land cover analysis was limited by the number of cloud cover free imagery for some years for the desired period - mid dry season (e.g. 1993, 1998 imageries). This situation influenced the land cover change analysis and thus all results should be considered with caution. In order to overcome the above referred limitations the team has taken several actions namely:

1. The sampling was designed to get as much information as we could. Interviews were carried out with community leaders and park managers, while ecological data was collected along transect with sampling plots allocated in strategic distances from the village to address forest degradation.
2. Ecological modeling was only used to investigate the responses of the ecosystem to climate changes and the inherent limitation recognized in results interpretation.

3. Forest degradation was only considered as loss of forest to agriculture, to minimize errors associated with Landsat medium resolution and cloud cover.

3. Results

3.1. Miombo woodland habitat change

The land cover map of QNP for the year 2013 is presented in Figure 5 and Table 5. In general, miombo woodlands composed the biggest vegetation cover of the park, occupying about 38.9 % of the total area, the same figure found by Bandeira et al. (2007). Agriculture/settlements areas cover 4.6 % of park. In general, block A presented the biggest area of miombo woodlands with about 59.15 % of the block's total area. Block C had the lowest coverage of miombo with only 6.67 % of its area (Table 5). Other types of vegetation (dense forests, open woodlands/grasslands and thickets) occupied 89% of this block.

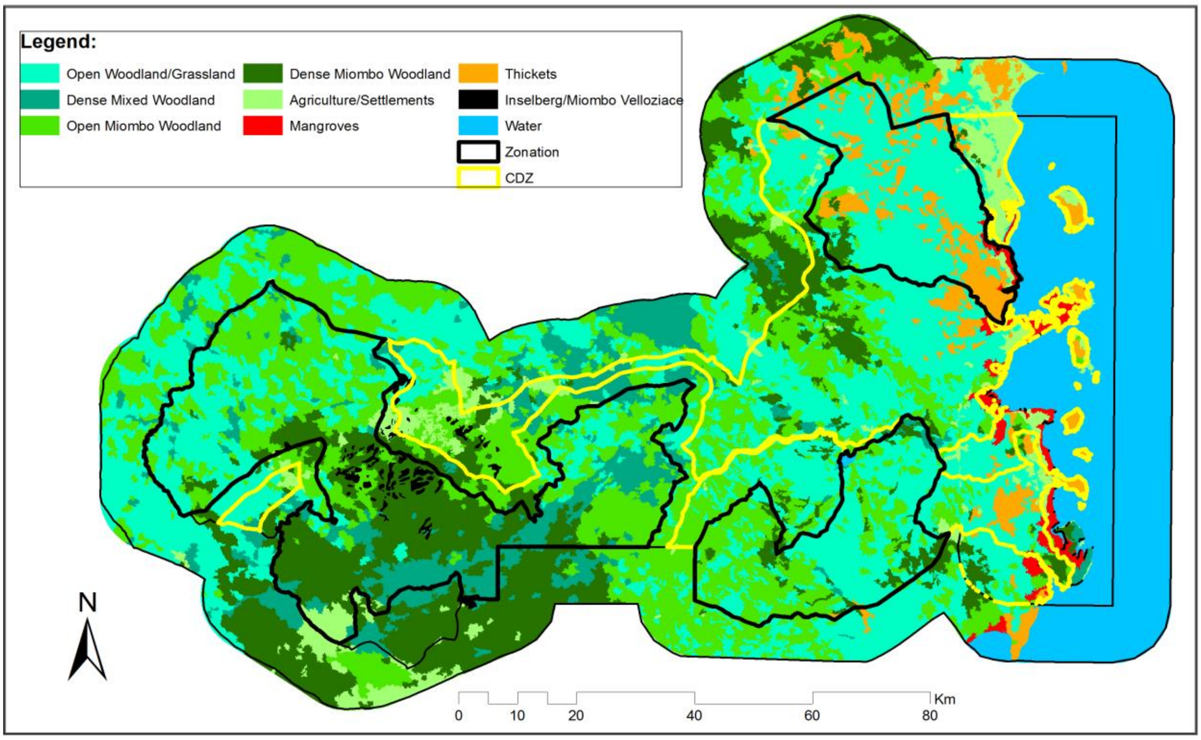

Figure 5. Land cover map in QNP at 1:250000 for the year 2013.

Table 5. Area (Km^2) per land cover per block for Quirimbas National Park.

Land cover	Block A		Block B		Block C		Grand Total	
	(Km^2)	**(%)**	**(Km^2)**	**(%)**	**(Km^2)**	**(%)**	**(Km^2)**	**(%)**
Open miombo woodland	748.03	31.47	321.42	38.00	30.07	3.46	1099.52	26.87
Dense miombo woodland	610.93	25.70	79.38	9.39	28.58	3.29	718.90	17.57
Inselbergs/Miombo-Velloziace	47.30	1.99	0.00	0.00	0.00	0.00	47.30	1.16
Sub-total Miombo woodland	*1,406.26*	*59.15*	*400.8*	*47.39*	*58.65*	*6.67*	*1,865.72*	*45.60*
Dense mixed woodlands	398.12	16.75	14.47	1.71	0.00	0.00	412.59	10.08
Open woodland/Grassland	525.79	22.12	423.84	50.11	592.02	68.19	1541.65	37.68
Thickets	0.00	0.00	1.97	0.23	187.92	21.64	189.88	4.64
Sub-total Other formations	*923.91*	*38.86*	*440.28*	*52.06*	*779.94*	*89.83*	*2,144.12*	*52.41*
Mangroves	0.00	0.00	0.00	0.00	16.14	1.86	16.14	0.39
Agriculture/Settlements	47.11	1.98	0.54	0.06	11.59	1.33	59.24	1.45
Water	0.00	0.00	4.13	0.49	1.91	0.22	6.04	0.15
Grand Total	**2,377.28**	**100**	**845.75**	**100**	**868.24**	**100**	**4,091.27**	**100**

The accuracy assessment indicated that the classification was performed with very good accuracy (GAI=82% and K=78.83%; Sartori, 2006). The former indicates that the likelihood that the classes obtained by Landsat 8 images match the ground is 82% and the latter reveals the classification perfection. Annex IV presents the error matrix for the land cover map.

3.2. Land cover changes

The land cover changes for the period 2008 - 2013 revealed that, the open miombo class did not change substantially. There were substantial transitions from open miombo woodland to dense miombo woodland (3101 ha). Figure 6 shows the change between different land cover for 2008 and 2013.

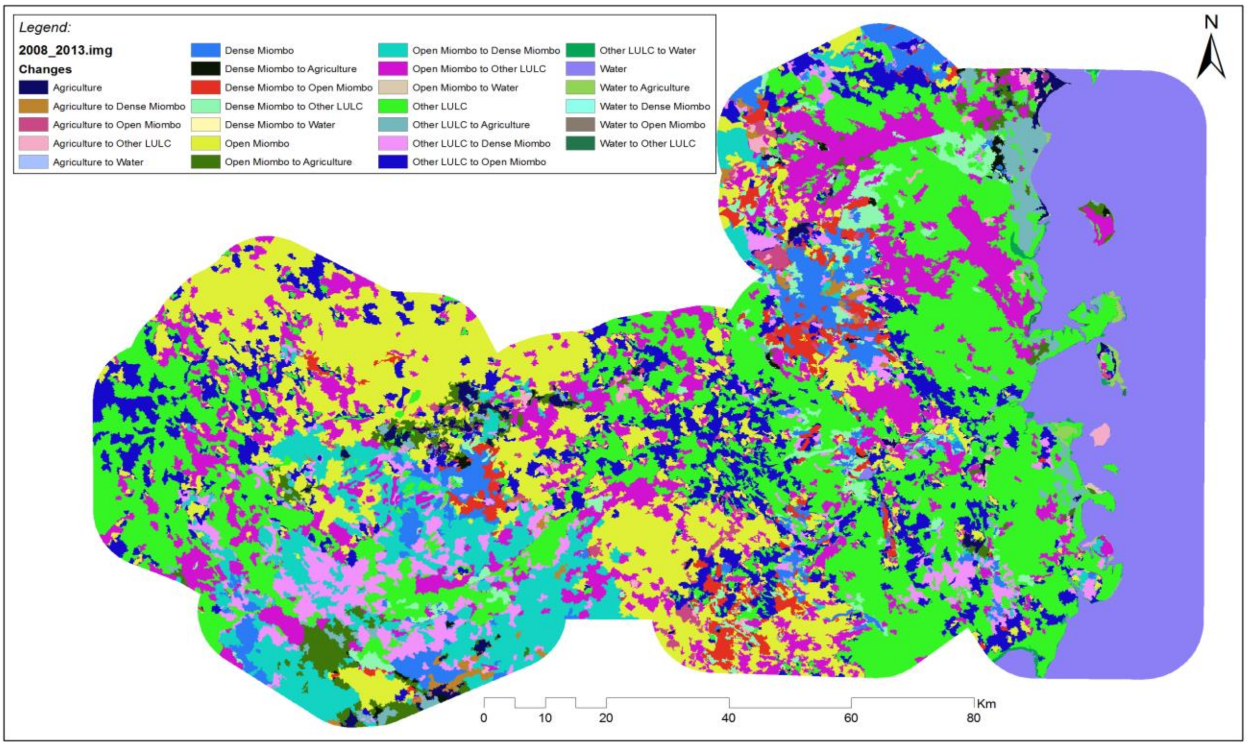

Figure 6. Land Cover Change between 2008 – 2013.

Figure 7 indicates the trends in miombo woodlands during the 22-year period (1991-2013), revealing an overall increase in dense miombo but a decrease in open miombo and agricultural area in the last decade. Our results indicate that open miombo woodlands were essentially lost to agriculture (about 778 ha in the last decade), while the corresponding open miombo recovery from agriculture was only 300 ha, i.e. half of the loss. Dense miombo loss to agriculture was only 100 ha in the last decade, but the corresponding recovery was the double. This result must be interpreted with caution as it might be related to errors in image classification.

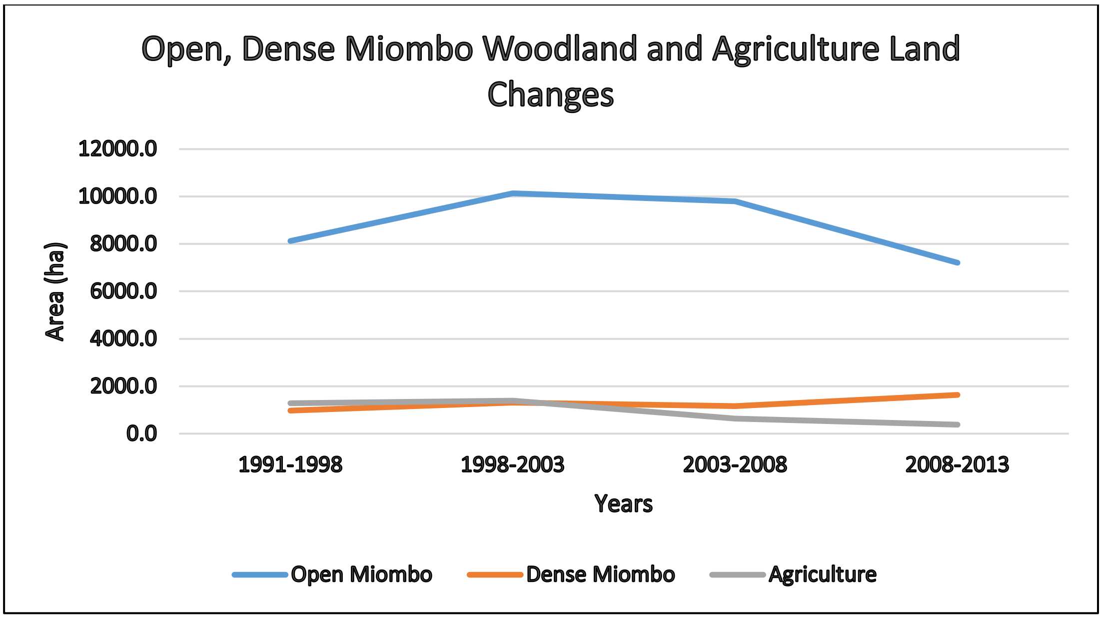

Figure 7. Open, Dense miombo woodland and agriculture land changes.

Block A had the highest loss of miombo to agriculture (3500 ha in the last decade), followed by Block C (400 ha) and Block B (49 ha). However, Block A had also the greatest miombo recovery in the last 10 years of about 700 ha, while Block B and C had 100 ha and 92 ha, respectively.

Figure 8 presents the spatial distribution of the degraded areas (loss of miombo to agriculture) between 2008 and 2013, revealing that in general areas of miombo loss are located outside of the protection zones of the park (Blocks A-C), but the southern portion of Block A had a major loss of miombo to agriculture.

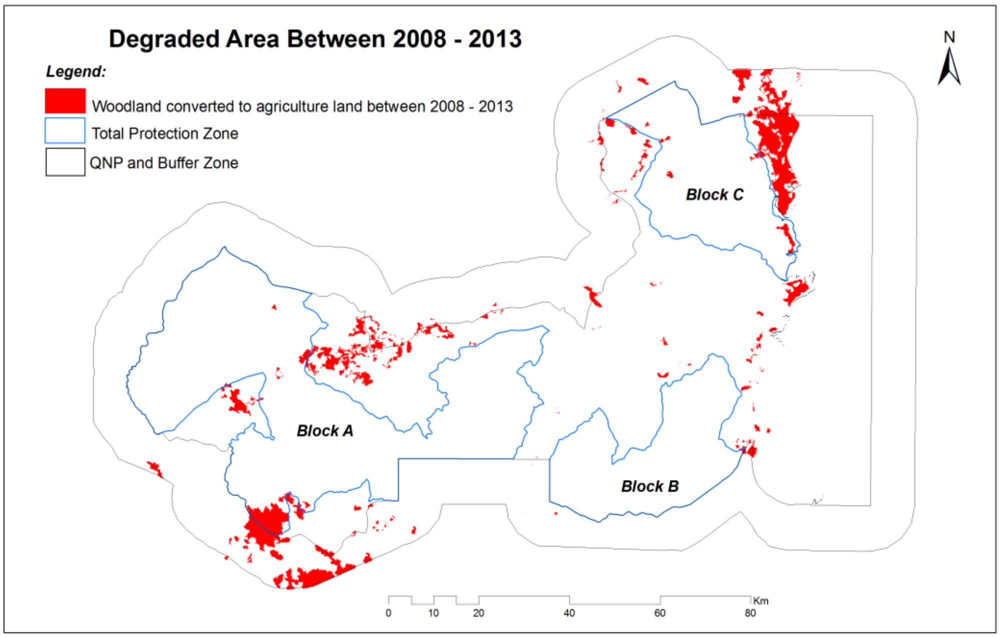

Figure 8. Degraded miombo (loss to agriculture) and QNP zonation.

3.2. Fire regime

The fire regime was analysed for a period of 14 years (2000-2014) revealing an inter-annual cycle of both fire density and intensity (Figure 9). The year 2003 presented the highest density and intensity of fires (0.78 fires per sq. km and 35 Kj^{-1}), but in general the inter-annual cycle was maintained over the years.

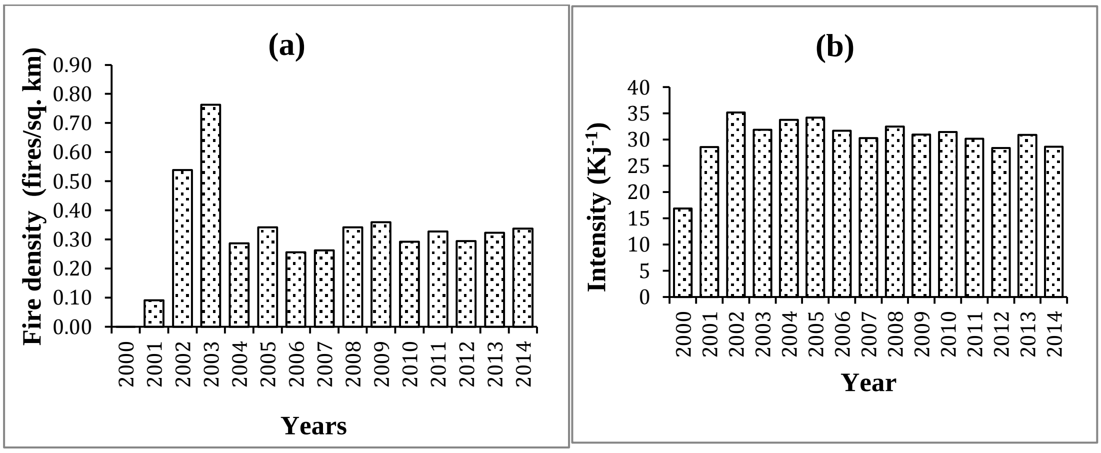

Figure 9. inter-annual variations in fire density (a) and intensity (b) in QNP.

The intra-annual variation in fire density and intensity revealed a pattern that is is associated with the rainfall distribution within a year (

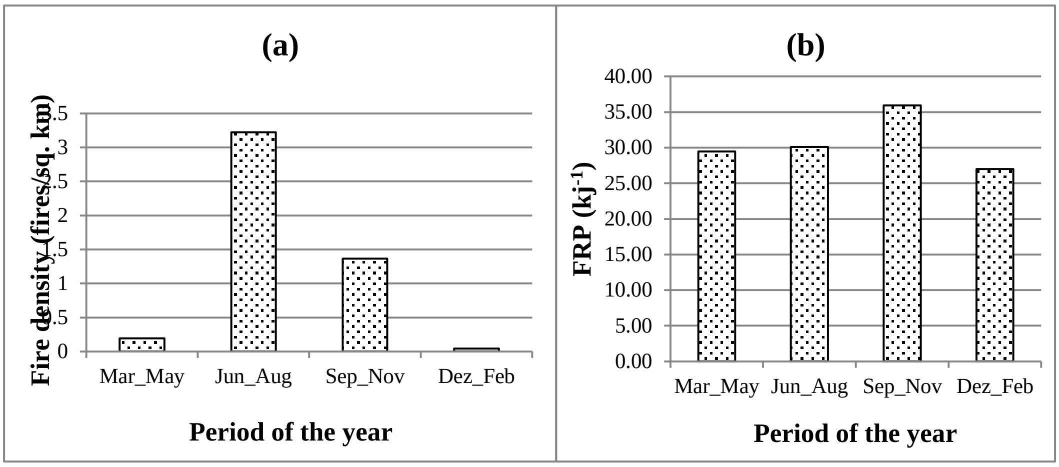

Figure 10). The peak of the dry season (June-August) showed the highest density (3 fires per sq. km) and intensity of fires (36 kj^{-1}).

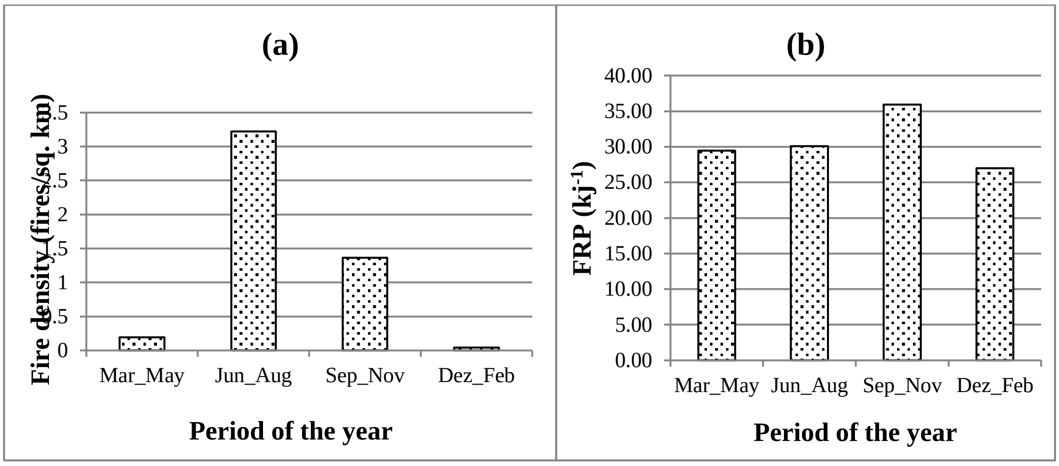

Figure 10. Mean seasonal variation of fire density (a) and intensity (b) for the QNP.

During the 14 year-period, the extent of area burned showed also an inter-annual variability with a peak in 2009 (2917 sq. km or 32% of the park;

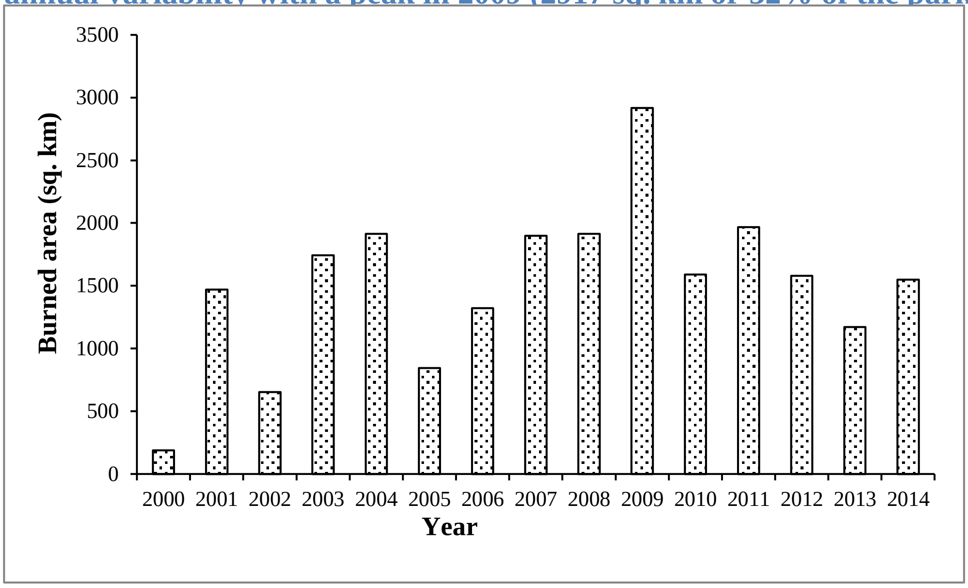

Figure 11). The spatial distribution of the burned area per year is presented in Annex V and indicates that the western (Meluco and Montepuez districts) and northern (Macomia District) parts of the park burned more than the rest, which is likely a result of high human population density and respective activities. Our analysis reveals that 21% of the park area burned every 2 years, which is a common fire frequency figure for the miombo woodlands in the region. This frequency allows woodlands recovery between fires, causing less damage to the ecosystem.

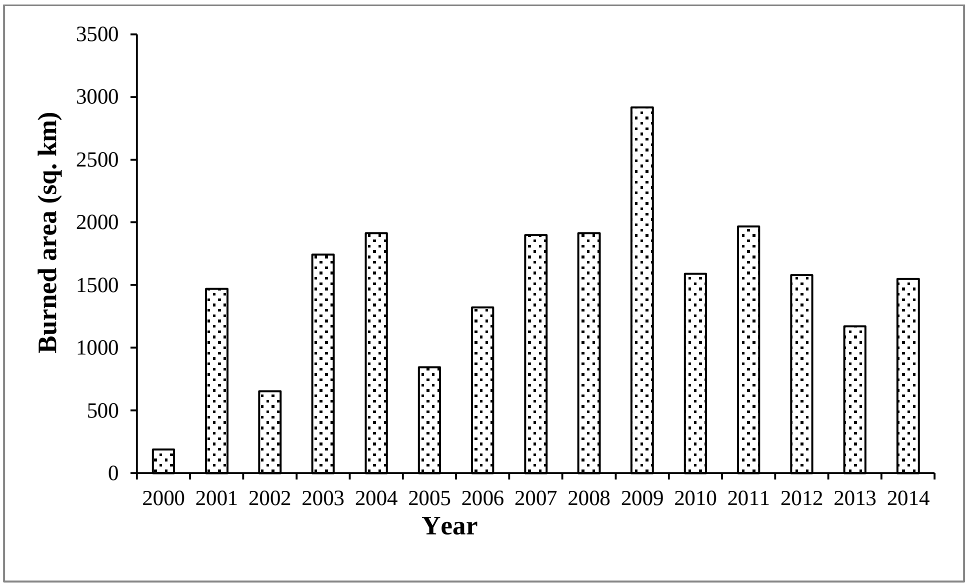

Figure 11. Burned area across the 14 years of study.

The spatial distribution of fire frequency for the 14 years (Figure 12) revealed higher fire frequency (annual fires) in the northern region in Macomia district, but most of the area presented either 1or 2 fires during the study period, i.e. low fire frequency. The western side of the QNP had a fire frequency of every 2-3 years.

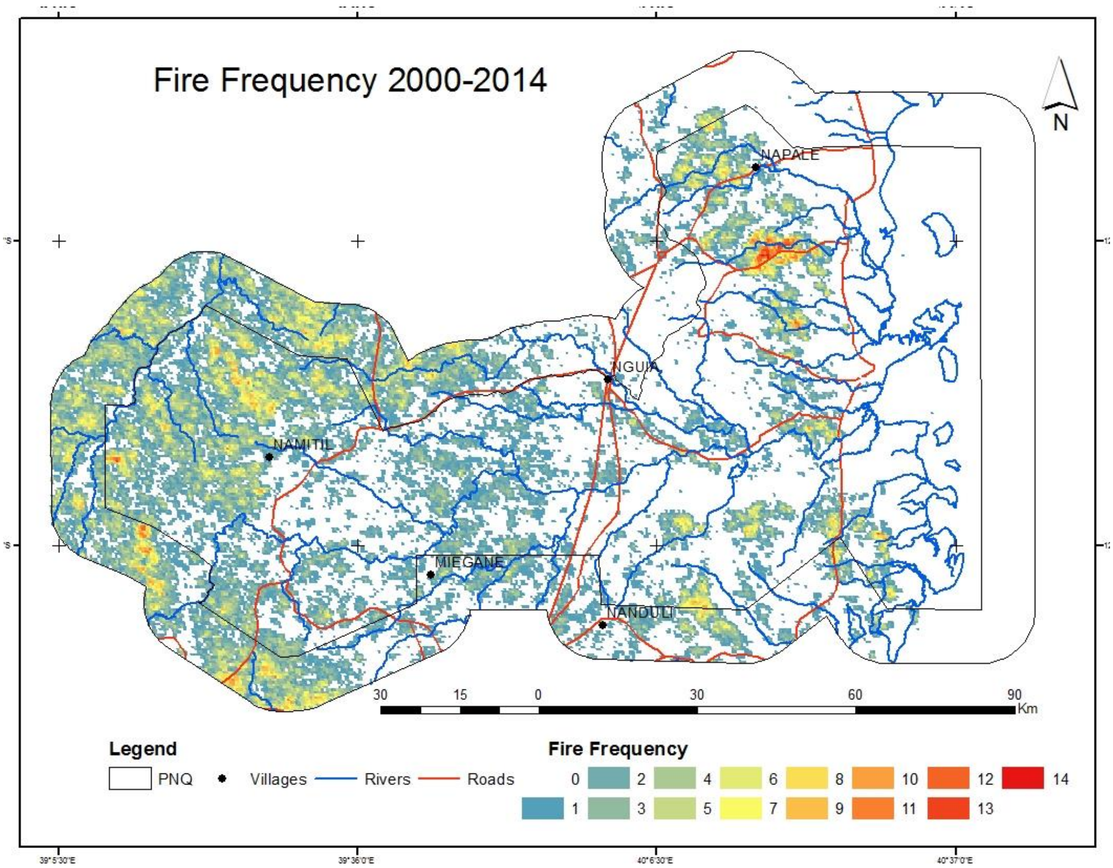

Figure 12. Spatial distribution of fire frequency for the period between 2000 and 2014.

3.3. Biodiversity assessments

3.3.1 Woodland structure and composition per park zone

Our study identified 117 tree species distributed, among 20 families (the dominant dominant family being Fabaceae) and corresponding to an abundance of 309 trees/ha. The woodlands are represented by typical miombo tree species such as: *Julbernardia globiflora*, *Brachystegia boehmii*, *B. spiciformis*, *Diplorynchus condylocarpon*, *Pseudolachnostylis maprouneifolia*, among others.

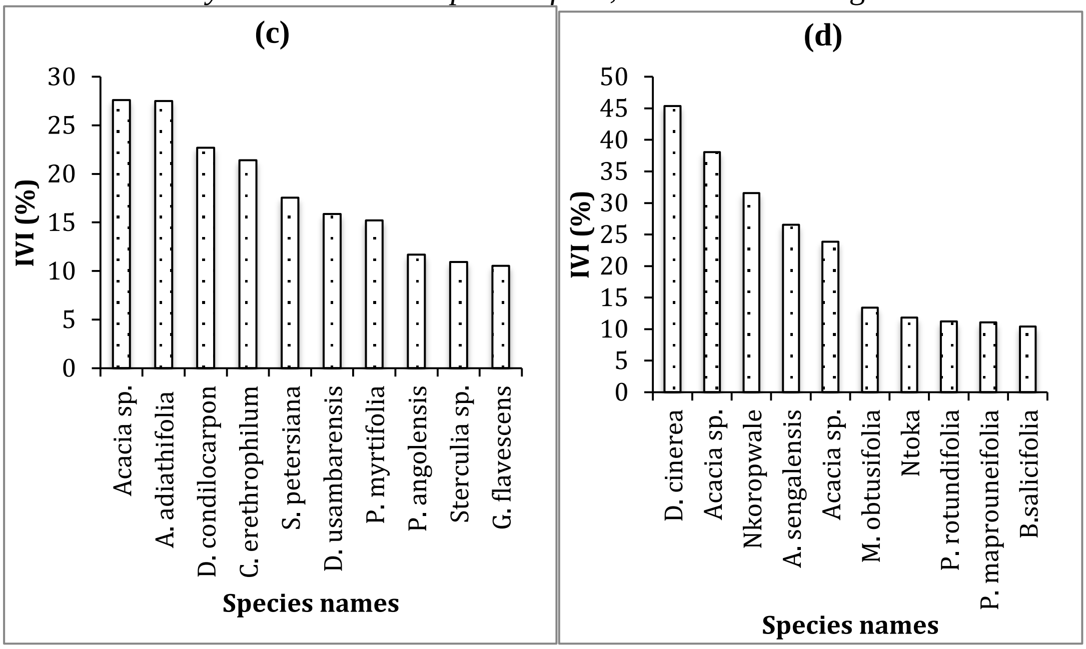

Figure 13 indicates the 10 ecologically most important species per park zone as given by the Index of Importance Value (IVI). The index combines distribution, abundance and dominance of a species in the ecosystem and thus provides a good description of species ecological importance in the ecosystem. Blocks A and B were dominated by typical miombo species, while Block C showed elements of coastal forest influence such as the predominance of *Acacia* and *Albizia* species, which usually occur in sandy soils and dry areas. The Nguia area (located in the community development zone- CDZ) showed indications of human influence such as the ecological dominance of *Dichrostachys cinerea*, a species that indicates degraded or human influenced habitats. In this area, miombo tree species were either absent (e.g. *Brachystegia sp*.) or less important (e.g. *J. globiflora*, IVI=7). It is worth mentioning the ecological relevance of species that represent resources to local communities in all zones (food, constructions materials, timber) such as: *Annona senegalensis, Vangueria infausta, Sclerocarya birrea, B. boehmii, D. melanoxylon, M. stuhlmannii*, among others.

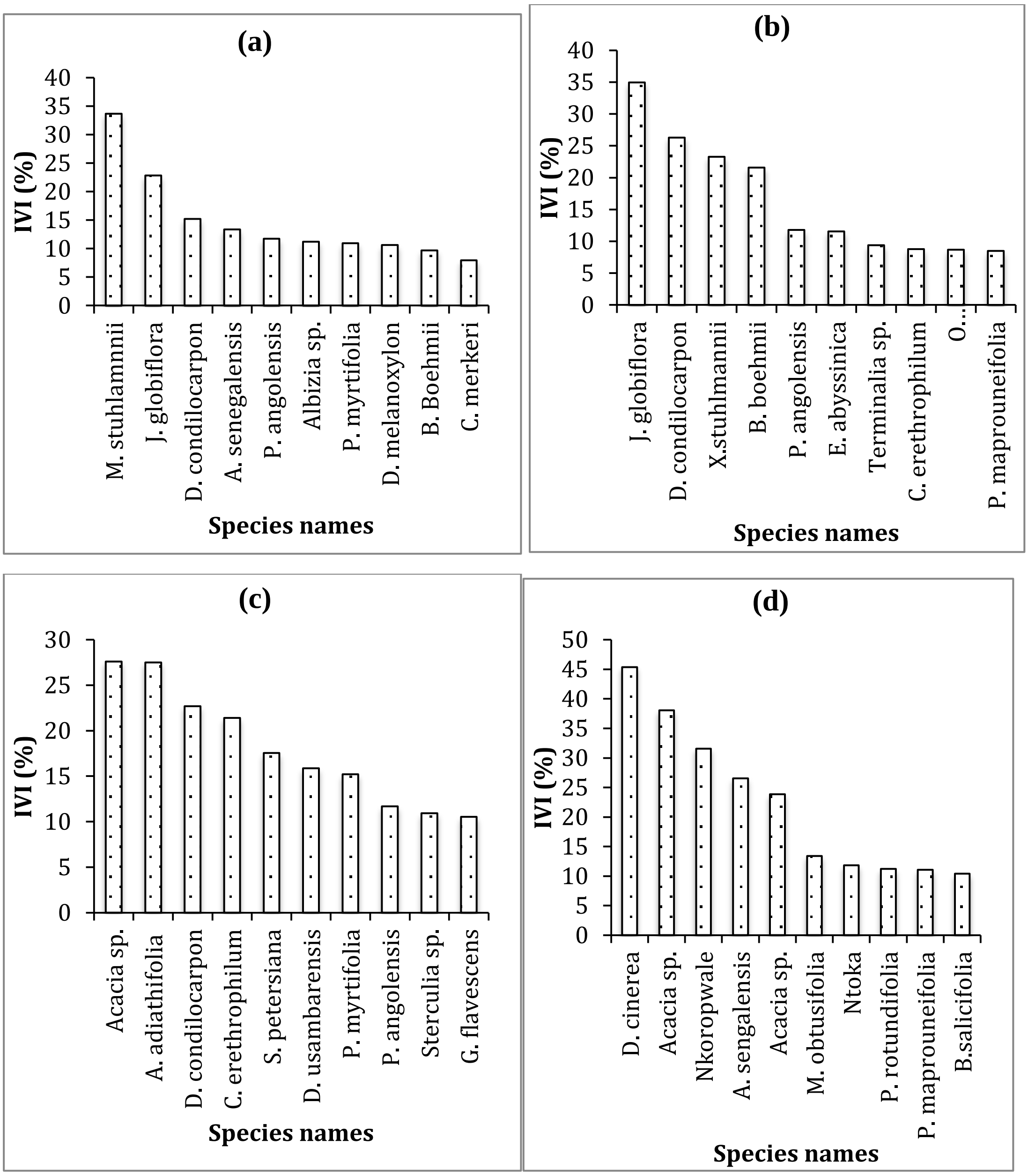

Figure 13. Index of Importance Value (IVI) per park zone for the 10 ecologically most important species; (a) Total Protection zone A (Villages Miegane and Namitil); (b) Total Protection zone B (Village Nanduli); (c) Total Protection zone C (Village Napala); (d) Community Development Zone (Village Nguia).

The Shannon Index (H') indicates that Block A and B had higher diversity of species (H'=3.45 and 3.20, respectively) and were richer in species (S=59 and 42, respectively) than Block C (H'=2.45; S=19) and CDZ (H'=2.26; S=27). The former zones are typical wet miombo of the northern miombo ecoregion (Frost, 1996), while zones C and CDZ approximate dry miombo woodlands. Species are evenly distributed in all zones (Pielou's equitability index, J'>0.80).

The ecosystem was in general of medium to high stock with a total basal area of 156 m^2/ha and mean volume of 49.9 m^3/ha. Table 6 compiles the volume stock of the main timber species per park zone, indicating that the Block A and B were better stocked, while Block C did not present any timber species. Block A presented the highest stock in biomass with 44,9 Ton/ha, followed by Block B with 14 Ton/ha, CDZ with 9 Ton/ha and finally Block C had only 4 Ton/ha. The latter is expected for degraded woodland in which soil compaction and erosion may limit grass development. The ecologically important species in each zone made up to 50% of the total biomass reinforcing their ecological importance in all zones.

Table 6. Volume stock (m^3/ha) of the main timber species in the QNP.

Species name	Timber Class (Forest and wildlife Regulation)	Volume (m3/ha) per Park Zone		
		A	**B**	**CDZ**
M. Stuhlmannii	First	2,63	0.12	0
J. globiflora	Second	3,11	1.99	0,23
P. angolensis	First	0,73	0,43	1,12
P. myrtifolia	First	0,29	0,00	0,2
B. spiciformis	Second	0,92	0,81	0
B. boehmii	Second	0.89	2.09	0
D. melanoxylon	Precious	0,36	0.18	0
Total (m^3/ha)		**8,03**	**1,24**	**1,55**
% of total vol.		**34%**	**10.7%**	**15%**

The diametric distribution for Block A and C approximated the inversed J-shaped distribution (**Figure 14**) indicating a stable stand (Lamprecht, 1990) in which removal of adult trees (both natural or human induced) is replaced by sufficient stock of natural regeneration. Block B presented an inversed J-shape but with a change to a bell-shaped curve in class 25 and 30 cm. CDZ had a diametric distribution that is typical of a perturbed area in which trees removal in several classes produces a diametric distribution with no particular trend.

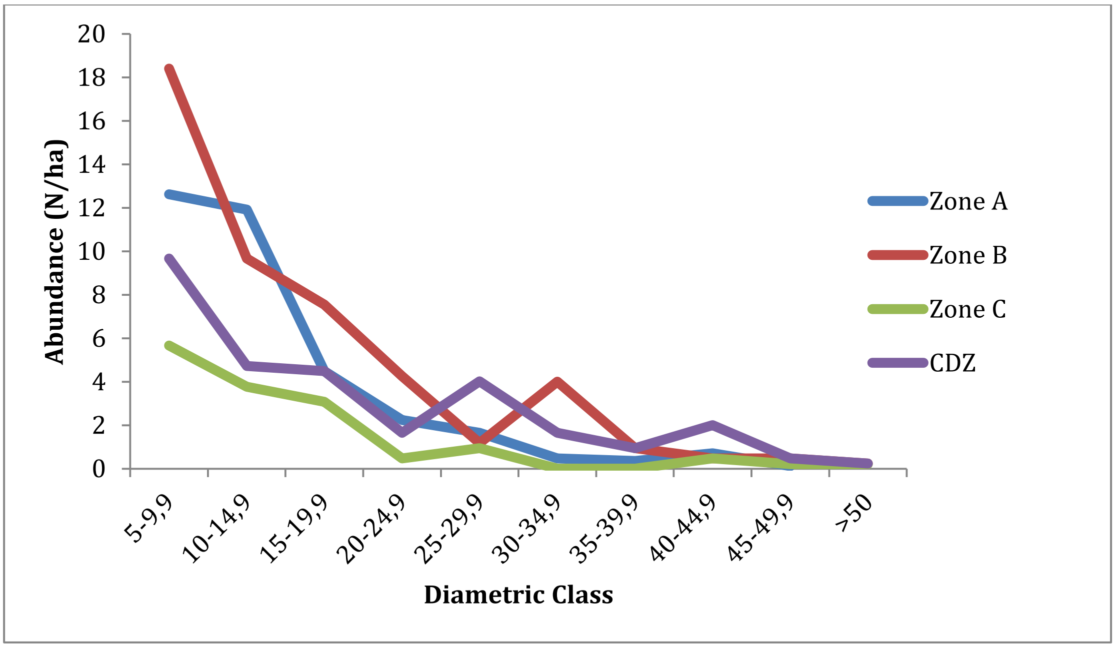

Figure 14. Diametric distribution of the woody component per park zone.

3.3.2 Woodland structure and composition per distance from the villages.

In order to assess the availability of resources we analysed the ecological parameters parameters at 1 km, 3 km and 5 km far from the main villages centres. The results indicate that the abundance of tree species was within the limits acceptable for miombo woodlands (Frost, 1996; Chidumyao, 2009) and were 341 tree/ha, 270 trees/ha and 307 trees/ha for 1km, 3km and 5km, respectively. The ecologically most important species varied according to the distance but in general miombo tree species (*J. globiflora*, *D. condylocarpon*, *M. stuhlmannii*, *B. boehmii*, etc.) were present at all distances (

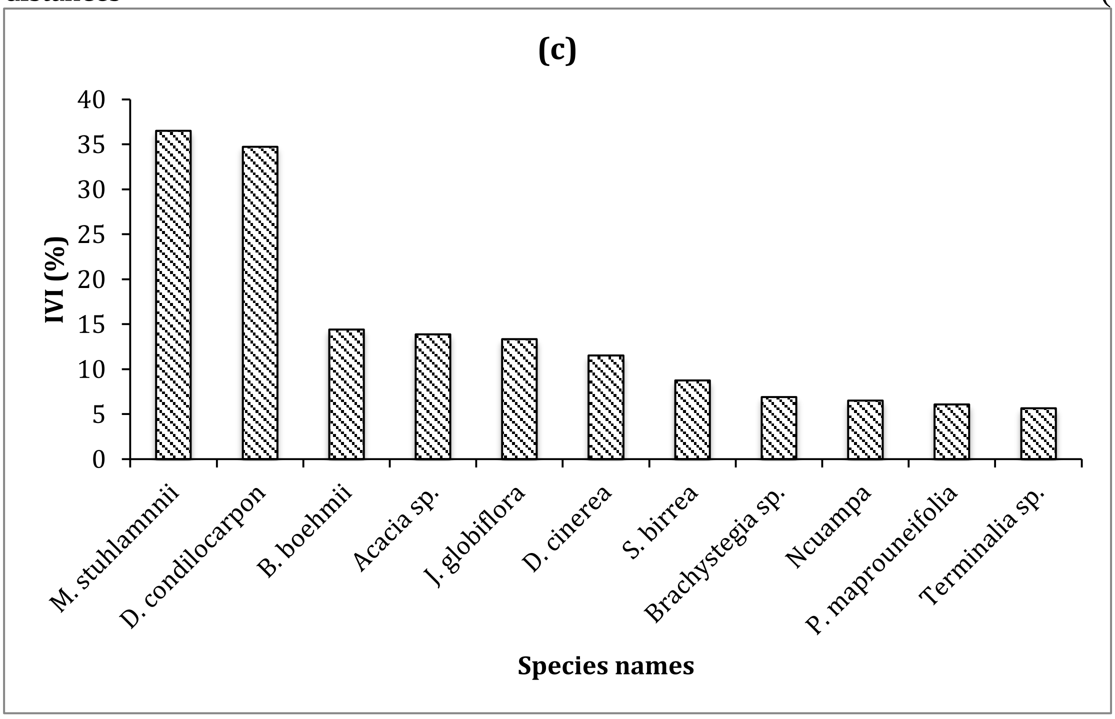

Figure 15). Close to the villages, important resource species such as *Annona senegalensis, Euclea natalensis* were ecologically important.

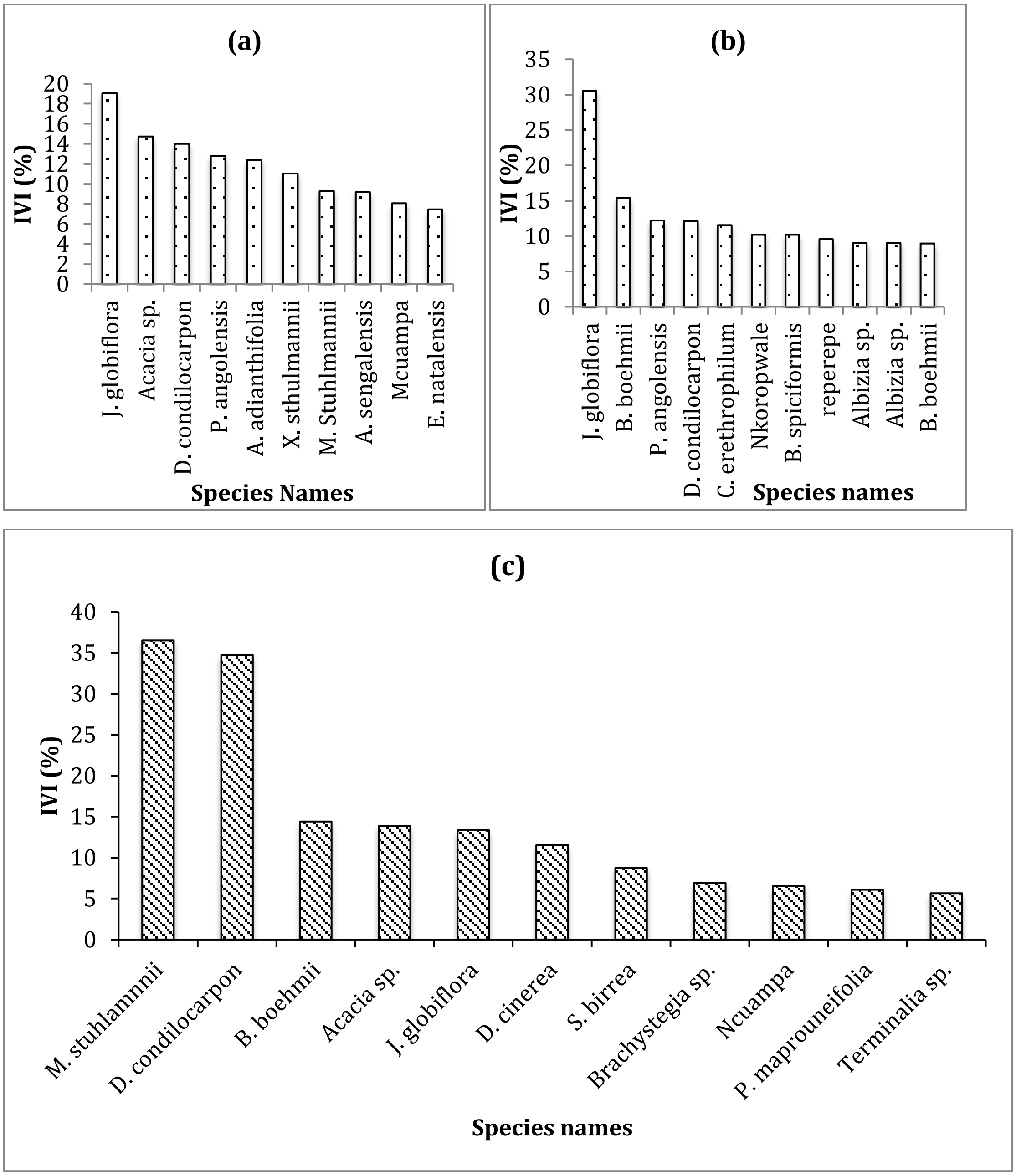

Figure 15. Importance Index Value of the 10 most important species for distances 1km (a), 3km (b) and 5 km (c).

The diametric distribution indicates an inverse J-shape diametric distribution across the different distances (

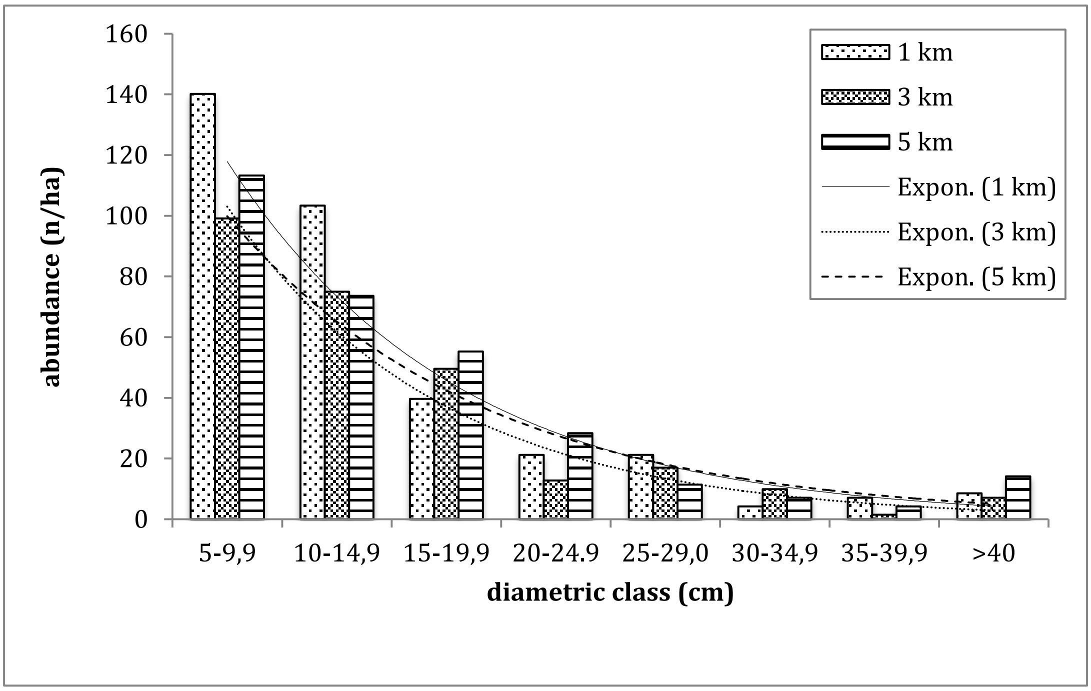

Figure 16), but the sites close to the villages had higher abundances of small trees (5-14.9 cm dbh), while 5 km distances had higher abundances of trees of 15 cm and higher (except for the classes of 25-29.9 cm and 35-39.9 cm).

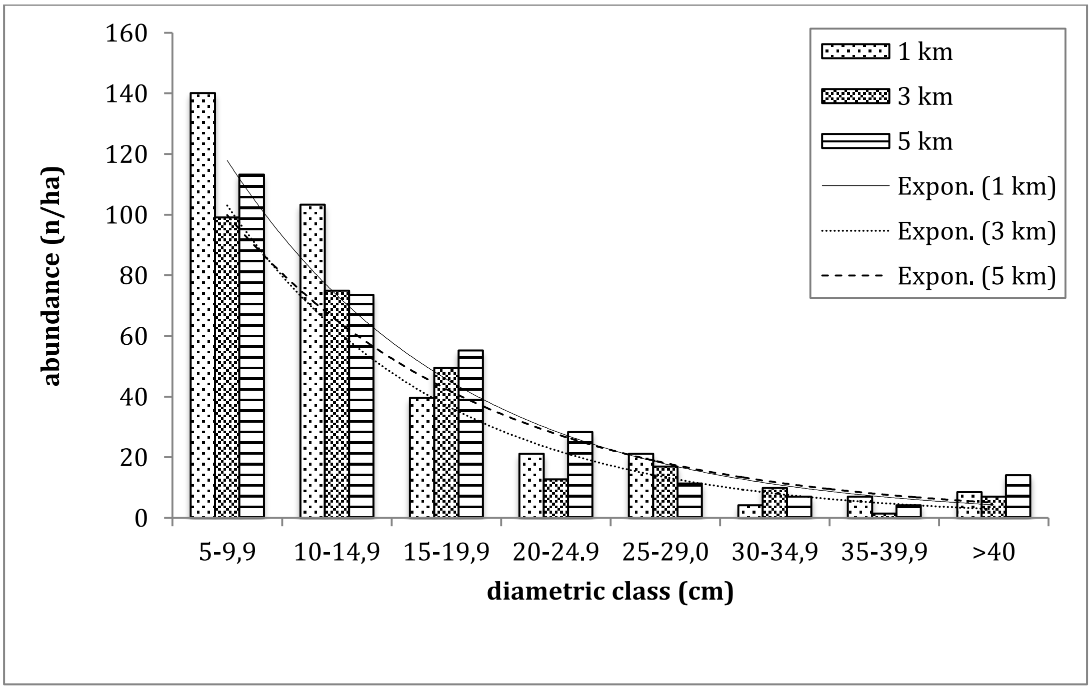

Figure 16. Diametric distribution of dbh per distance from the villages.

Species diversity (H’) and richness (S) were as higher at 1 km (H’=3.78; S=68) from the villages followed by 3 km (H’=3.48 and S=50) and 5 km (H’=3.26 and S=58), respectively while the woodlands were evenly distributed in all distances.

The woodland stock (volume and biomass) did not vary significantly among distances (Table 7).

Table 7. Ecosystem silvicultural parameters and diversity indices for QNP (Equal letters after the number indicate no statistical differences from the Tukey Kramer test at 5% significance level).

Parameter	**Distance from the villages (km)**		
	1	3	5
Volume (m^3/ha)	16.8a	12.6a	20.5a
Tree Biomass (Ton/ha)	1.46a	1.17a	1.36a
Grass Biomass	28766a	33177a	33839a
H’	3.78	3.48	3.26
J’	0.89	0.89	0.8
S	68	50	58

The main timber species (*M stuhlmanni, J. globiflora. P. angolensis, P. myrtifolia, B. boehmii* and *D. melanoxylon)* were all well represented in all distances both in terms of volume and biomass and the stocks were in general within the average for miombo woodlands. Altogether these species represent 11% of the total biomass and 10% of the total volume.

The habitat for wildlife consisted predominantly of open to medium density woodlands, with close to 50% of woody canopy cover. In the proximities to (1km distance) the habitat was more open, where most plots have less than tree canopy cover. Tree cover and tree height increased with the increase in from human settlements. Shrub cover did not change notably with changes in from villages (Figure 17 and

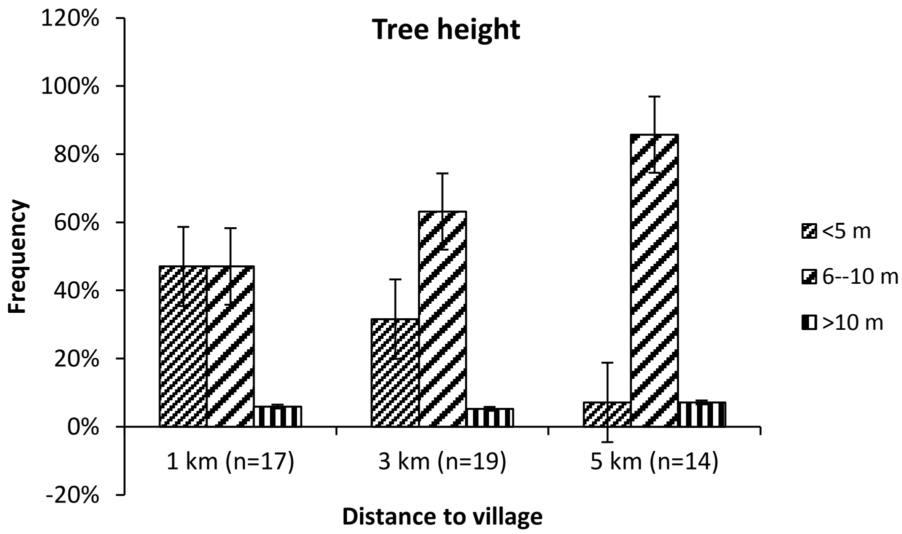

Figure 18).

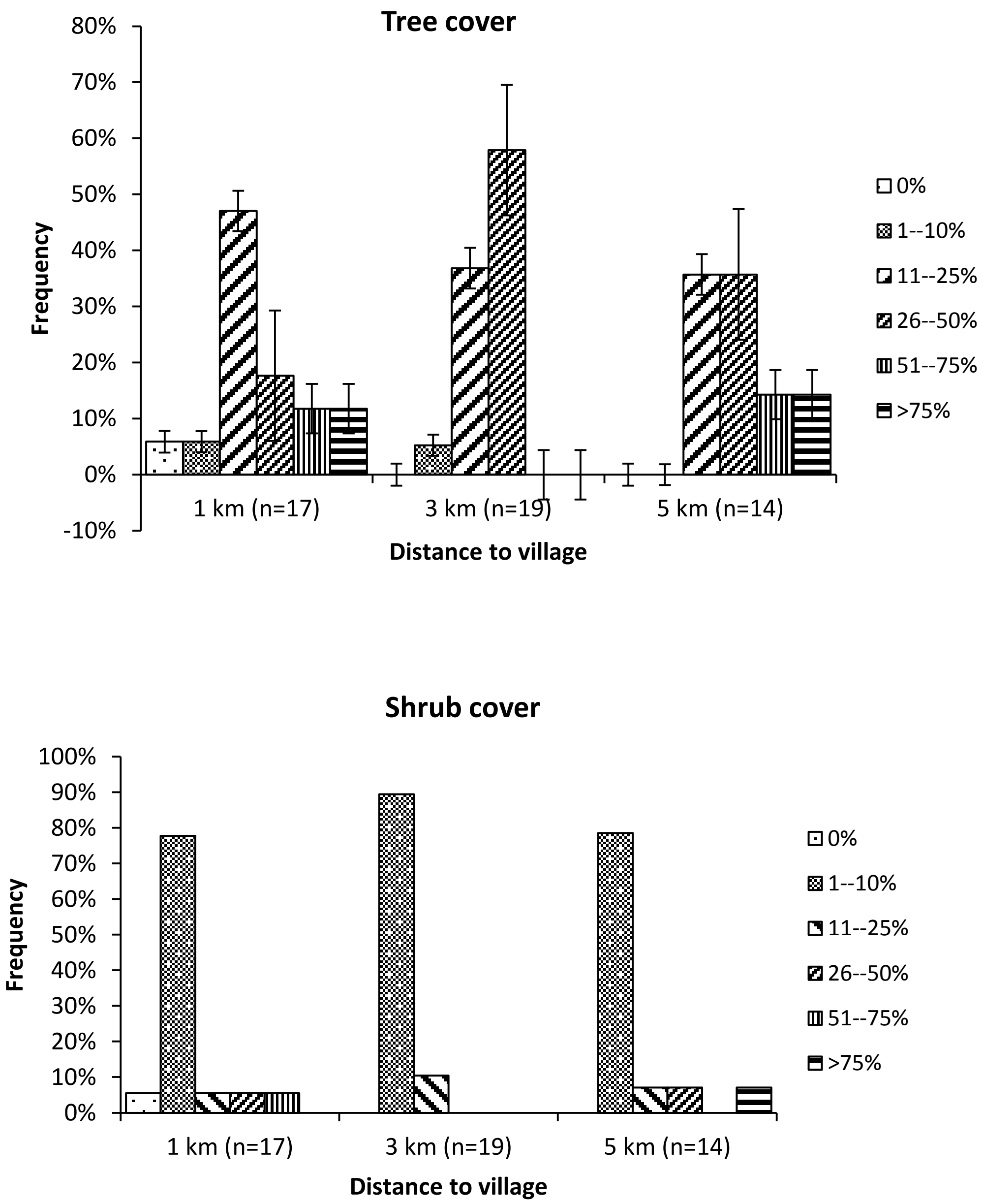

Figure 17. Prevailing habitat features in sampled plots.

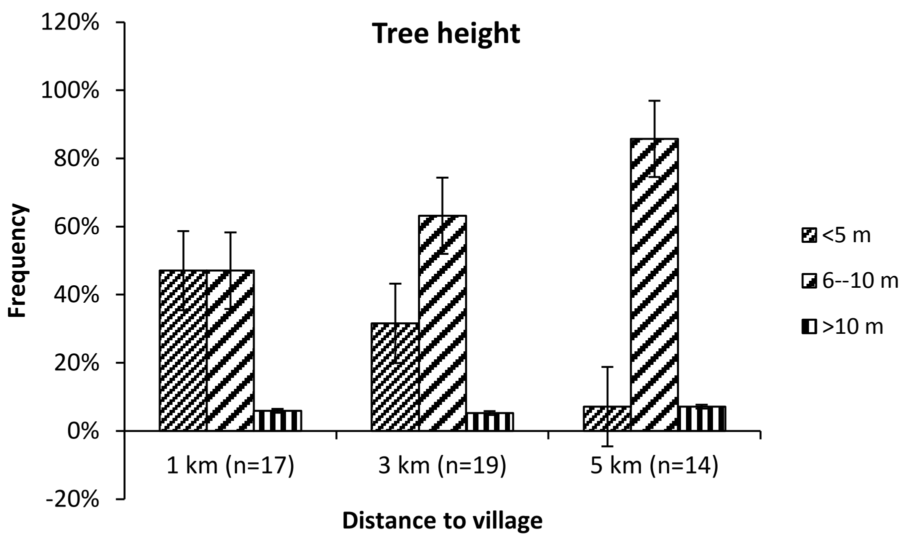

Figure 18. Prevailing habitat features in mammal sampling plots.

3.3.3. Fauna composition

The number of mammal species varied from 7 in intermediate distance (3km) to 11 species in shorter distance to the villages (1km). The frequency of occurrence of each mammal species did not differ significantly among distances to the villages. However, common duiker (*Sylvicapra grimmia*) and impala (*Aepyceros melampus*) were more frequently found close than away from human settlements, whereas kudu (*Tragelaphus strepsiceros*) showed the opposite trend (Figure 19).

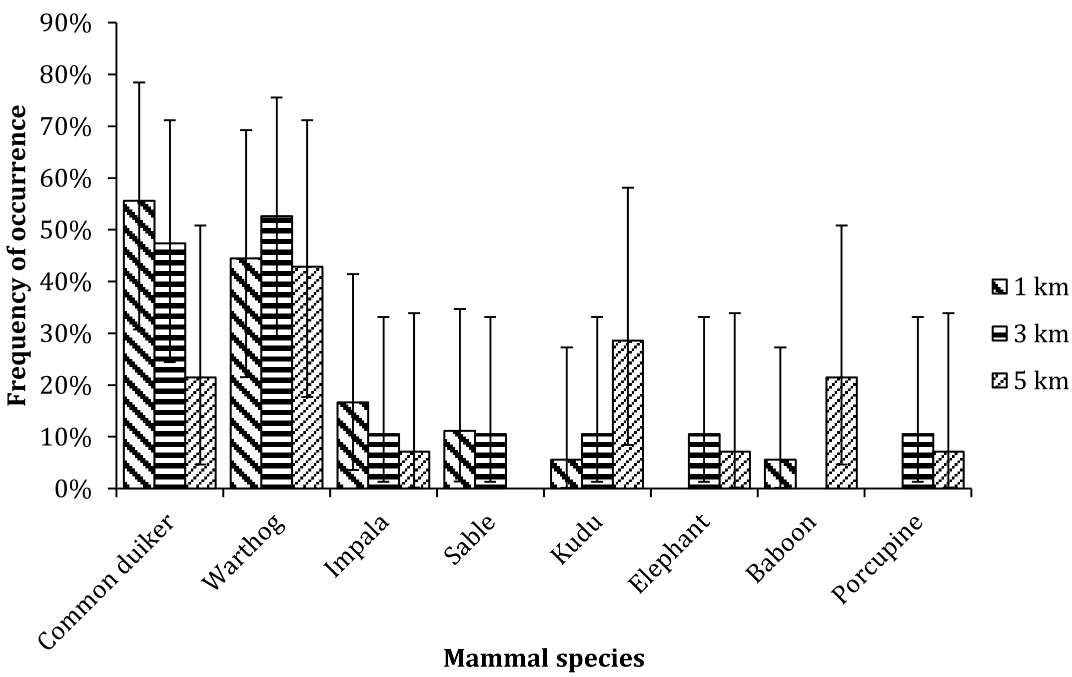

Figure 19. Frequency of occurrence of selected mammal species in plots surveyed in different distances from villages in miombo woodlands of the Quirimbas NP (vertical bars denote 95% binomial confidence interval for proportions).

Within 1km distance from the villages, common duiker and warthog (*Phacochoerus aethiopicus*) were the most encountered mammal species, accounting for approximately 35% and 30% of all mammal sightings, respectively. Kudu, elephant (*Loxodonta africana*) and yellow baboon (*Papio cynocephalus ursinus*) increased their relative frequency_with the increase in distance from village and reduction of human disturbance (Figure 20).

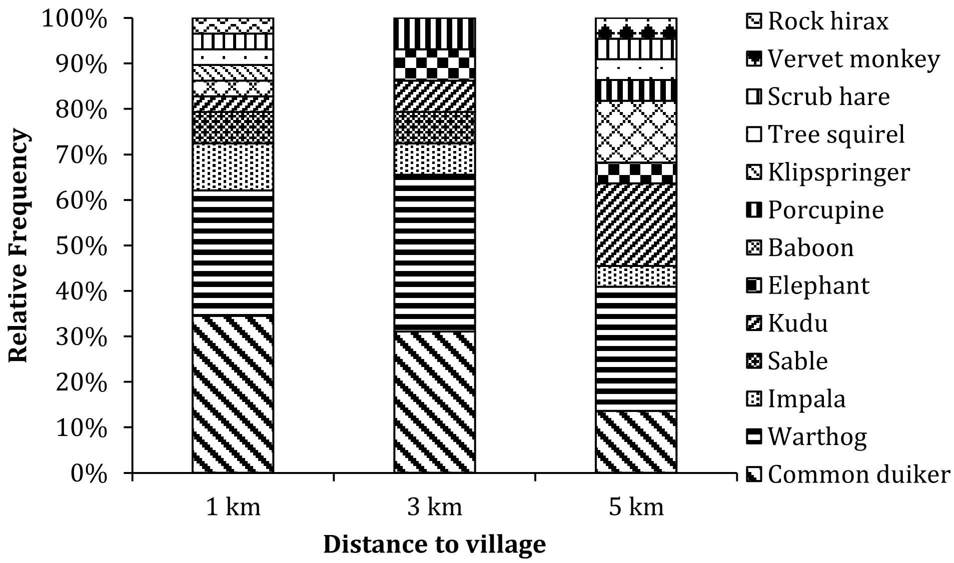

Figure 20. Relative frequency of selected mammal species in plots surveyed in different distances from villages in miombo woodlands of the QNP.

Poaching is a serious threat to fauna diversity and abundance in the QNP. Data from the national elephant aerial count conducted in 2014 indicate a reduction of elephant population by approximately 50% in less than 10 years. Northern Mozambique, particularly QNP, Niassa National Reserve and adjoining areas are the areas most targeted by poachers for being part of the Rovuma landscape, which has large extent of relatively intact habitats supporting the largest population of African elephant in East Africa. For example, Craig (2011) documented an elephant carcass ratio (percentage of dead elephants seen in relation to all elephants seen - Douglas-Hamilton, 1996) of 15% in 2011. Craig (2013) reported a carcass ratio of 49% in 2013 and suggested that 480 – 904 (95% confidence range of the difference) elephants died between 2011 and 2013, i.e. approximately 240-450 *per annum*, while arguing that this could be an underestimate of elephant mortality in the park. Craig (2013) and Couto (2014) pointed out that elephant mortality caused by poaching is higher than the population growth rate, which threatens the long-term persistence of this keystone species in the ecosystem. The key driver of elephant poaching is the illegal international trade of ivory, mainly in the Asian market (Couto, 2014).

3.5. Socio-economic uses and importance of miombo woodlands

The sampled communities (Namitil, Nanduli, Napala, Nguia and Miegane) were different in terms of demography, available infrastructures and accessibility to main roads and belong to different protection zones of the QNP (Table 8). In general Nguia and Napala had better accessibility to tarred road and markets than the other villages.

Table 8. General description of sampled communities.

Community	District	Number of inhabitants	QNP Protection area	Year of establishment	Type and quality of access
Namitil	Meluco	408	Block A	1996	Dirt road in bad condition
Nanduli	Quissanga	1617	Block B	1969	Dirt road in bad condition
Napala	Macomia	883	Block C	1974	Dirt road in reasonable condition
Nguia	Quissanga	376	Community Development Zone	1992	Tarred road
Miegane	Ancuabe	1727	Block A	1993	Trail in very bad condition

3.5.1. Main ecosystem services from the miombo woodlands

A total of 193 forest resources were cited by both individual and group respondents. A general description of the resources is presented in Table 9 and the respective detailed information is available in Annex VI.

Table 9. Number and type of forest resources mentioned in the socio-economic survey, both during semi-structured interviews and discussion groups.

Type of resource	Use	Number of resources mentioned in interviews	Number of resources mentioned in groups	Number of resources common to both samples
Plants	Food	70	61	33
Plants	Medicine	1	9	1
Plants	Construction and transformation	15	23	9
Plants	Fuel	1	2	1
Animals – vertebrates	Food	10	26	8
Animals – Invertebrates	Food	8	7	6

Fungi	Food	18	13	7
Honey and derivates	Food and medicine	2	4	2
Soil	Construction and transformation	0	2	0
TOTAL		124	144	67

Main ecosystem services identified were the provisioning of food and working materials. The forest resources more consistently mentioned in semi-structured interviews from all five communities and across genders is “iulo” (mushroom), followed by “minana” (tuber) (

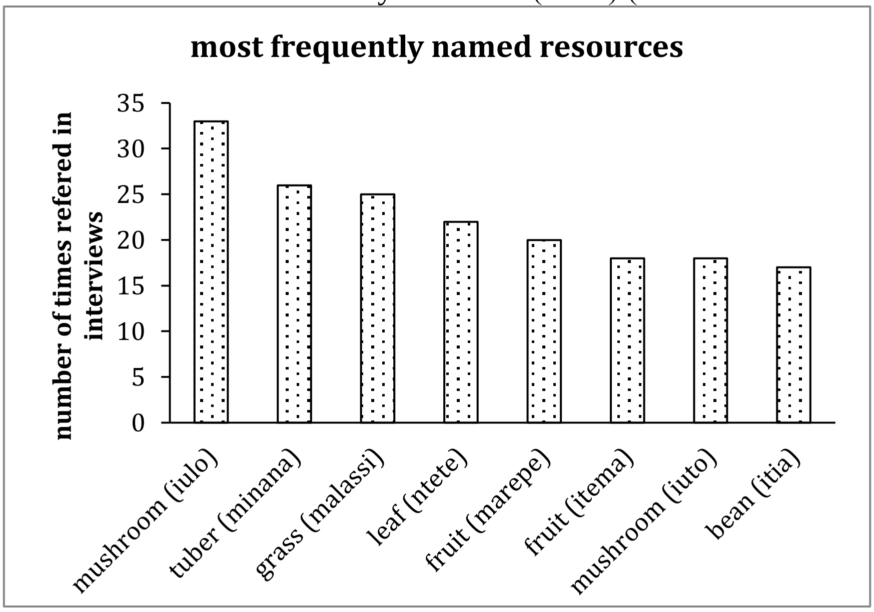

Figure 21). The majority of cited resources were used as food, namely mushrooms, tubers, beans, leaves, fruits and invertebrates; but construction materials (thatching grass and bamboo) and palm fibres for the production of mats and baskets were also commonly referred (

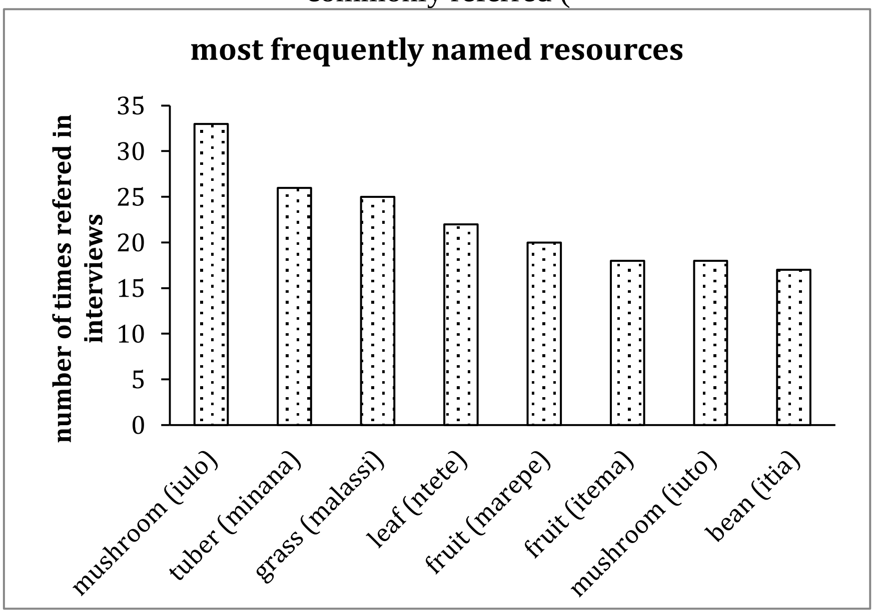

Figure 21).

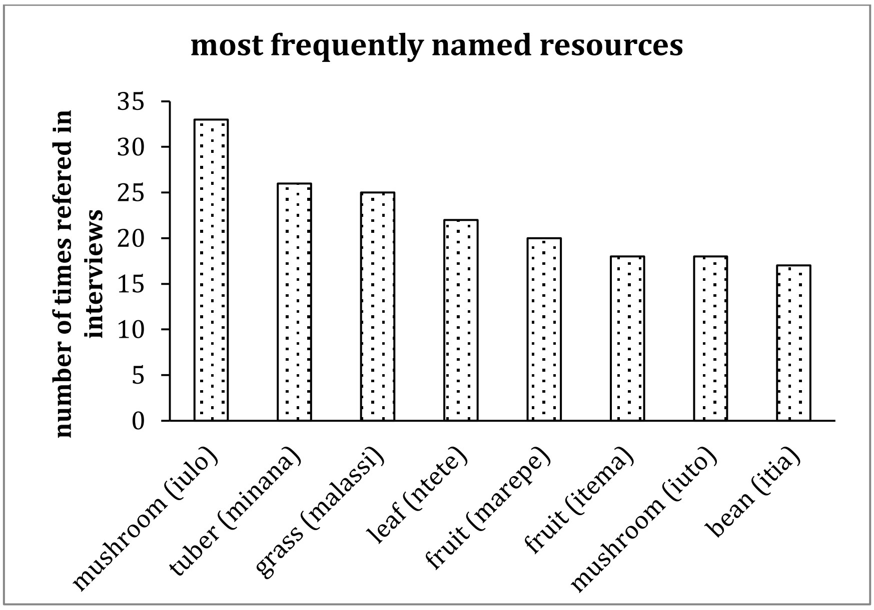

Figure 21. Frequency of citations of top mentioned forest resources, amongst interviewees in all five communities and across both gender.

Food resources were also the most cited in the group discussions, followed by raw materials for house construction and for transformation (vegetal fibres) (Figure 22).

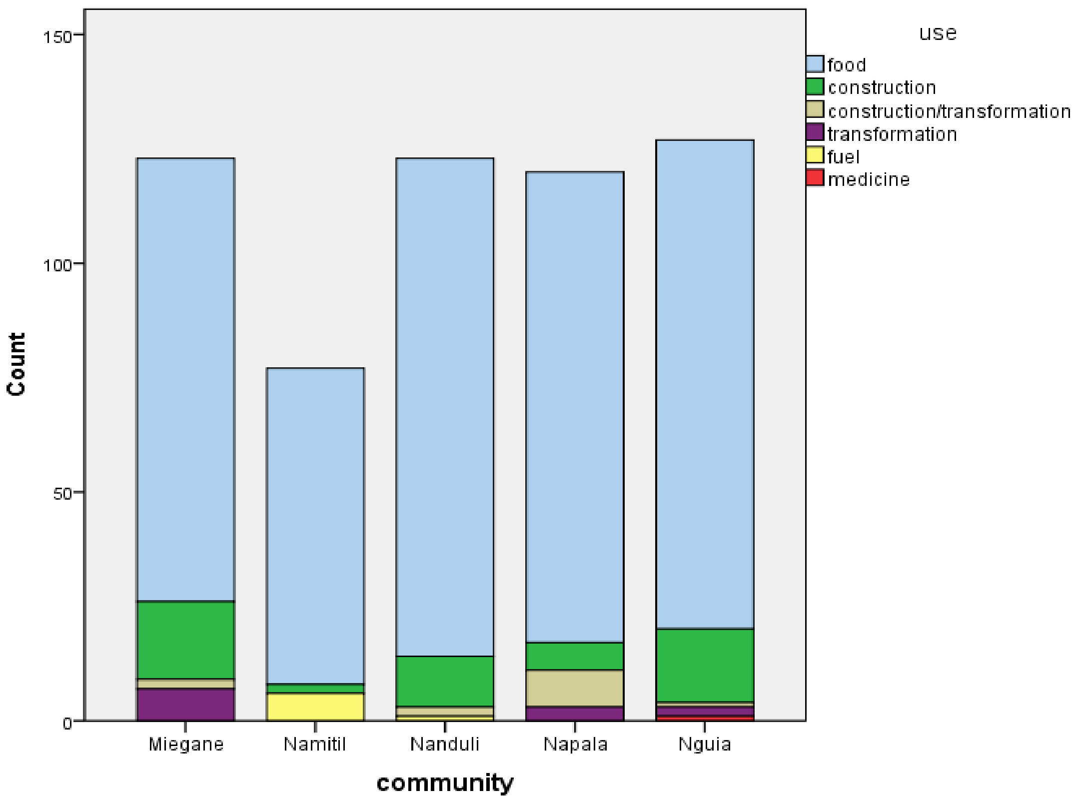

Figure 22. Total number of forest resources mentioned per type during discussion groups in sampled communities.

Climate regulation and soil erosion control were also mentioned as ecosystem services provided by forests. The community leader and a few interviewees from Napala village recognized the impact of deforestation and uncontrolled fires on precipitation and soil quality.

Seasonality and availability: Many food forest resources are only available during the rainy season (Figure 23). Mushrooms and invertebrates are mostly present during the rainy season (Figure 24). There is considerable lower number of food resources available during the dry season and year-round.

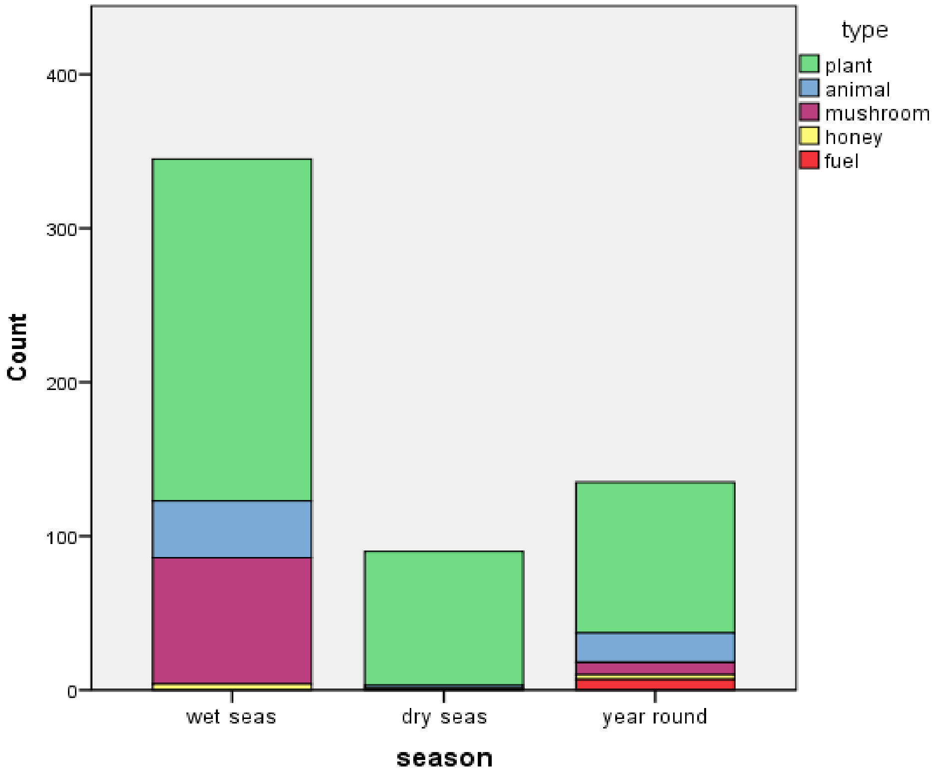

Figure 23. Season availability of forest resources per type, from semi-structured interviews in sampled communities.

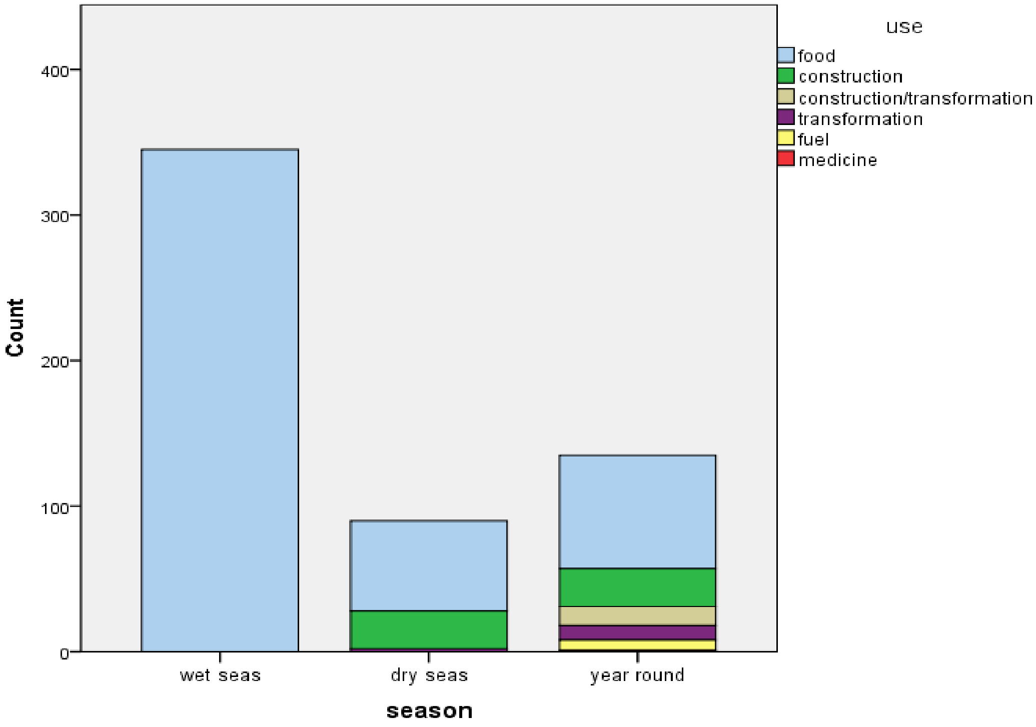

Figure 24. Season availability of forest resources per use, from semi-structured interviews in sampled communities.

Scoring/ Importance of forest resources: Fruits were the most cited resources used from the forest, but their average importance for family life is generally low (Score 1). More than half of "other food" (mushroom, ltuber, beans, le leaves) were in average very important, except for invertebrates, which were nearly all considered of low importance. All fuel, construction and transformed material were consistently rated as very important (Score 3) (Figure 25).

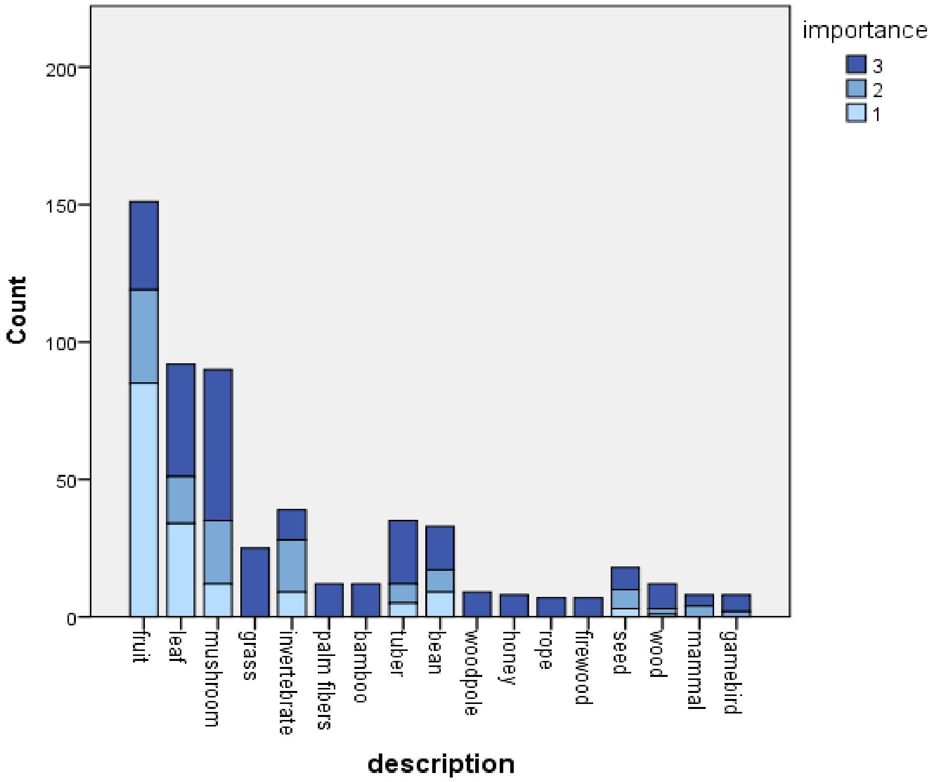

Figure 25. Distribution of the importance score for different groups of forest resources cited in semi-structured interviews.

Accessibility of resources: The majority of forest resources are collected within 1 hour walking distance (about 2 km) from the house of the interviewees (distance category 1). Resources collected further than 2 hours away were mostly classified as very important, so justifying the effort made (categories 2 and 3). The number of resources collected was lower for distances longer than 6 hours away (category 4) (Figure 26).

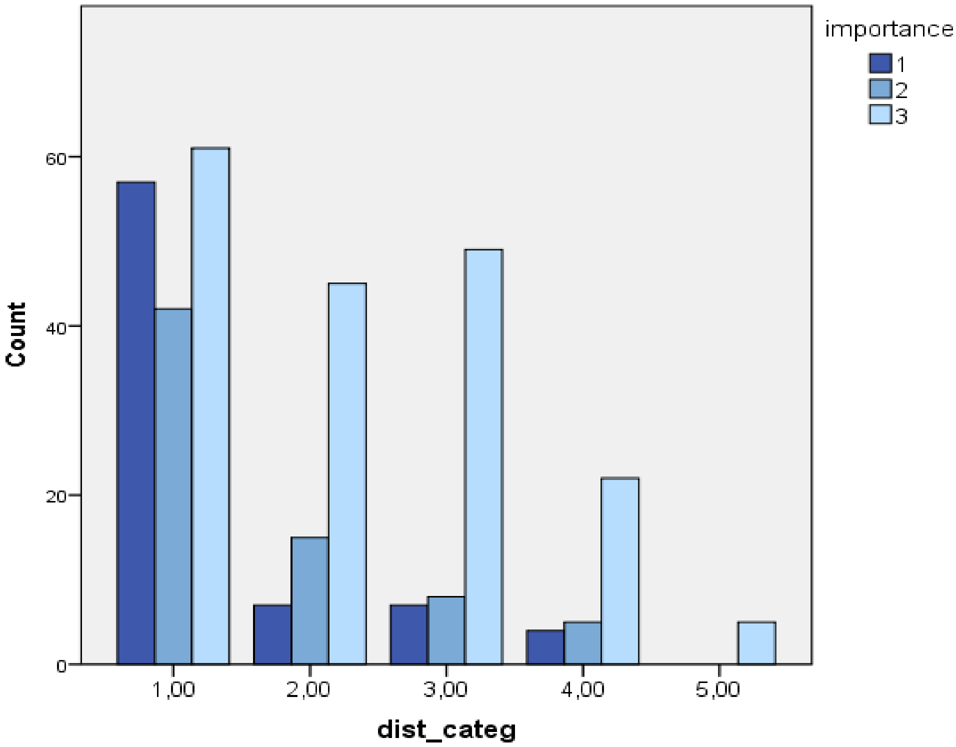

Figure 26. Frequency of responses and importance score of the forest resources collected within increasing distance categories (1- less than 1 hour; 2-more than 1 and less than 4 hours; 3- more than 4 and less than 6 hours; 4 – more than 4 hours walking distance).

Subsistence and commercial relevance of forest resources: Forest resources constitute a safety net for lean periods of food provisioning from agriculture. But they have also an increasing commercial value, mostly promoted in the communities with easier access to trading centers and from outsiders (Napala and Nguia) (Figure 27).

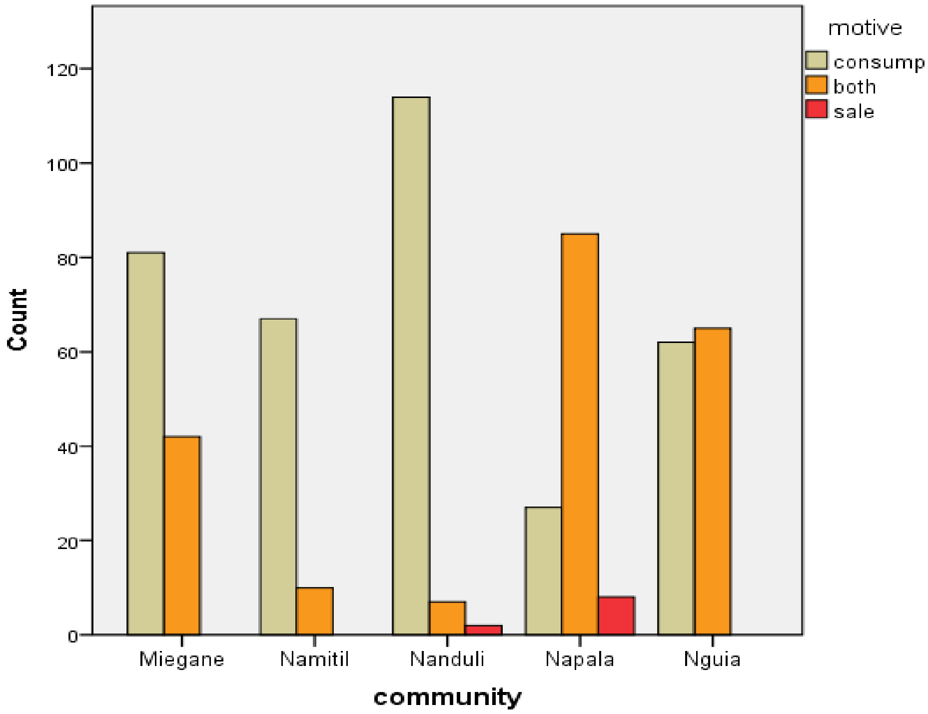

Figure 27. Frequency of responses for the motive of collection of forest resources from semi-structured interviews: 1- for household consumption; 2-for both household consumption and sale; 3-for sale).

The type of resource also influences its commercial value. Within food resources, mushrooms and tubers were mostly referred as used for both consumption and sale. Contrarily, leaves and invertebrates are collected almost exclusively for household consumption. Construction and transformed materials are mostly collected for both household use and sale, with wood being the only resource consistently referred as collected for commercialization and never mentioned as just for subsistence. Firewood was always mentioned as collected for household consumption only (Figure 28).

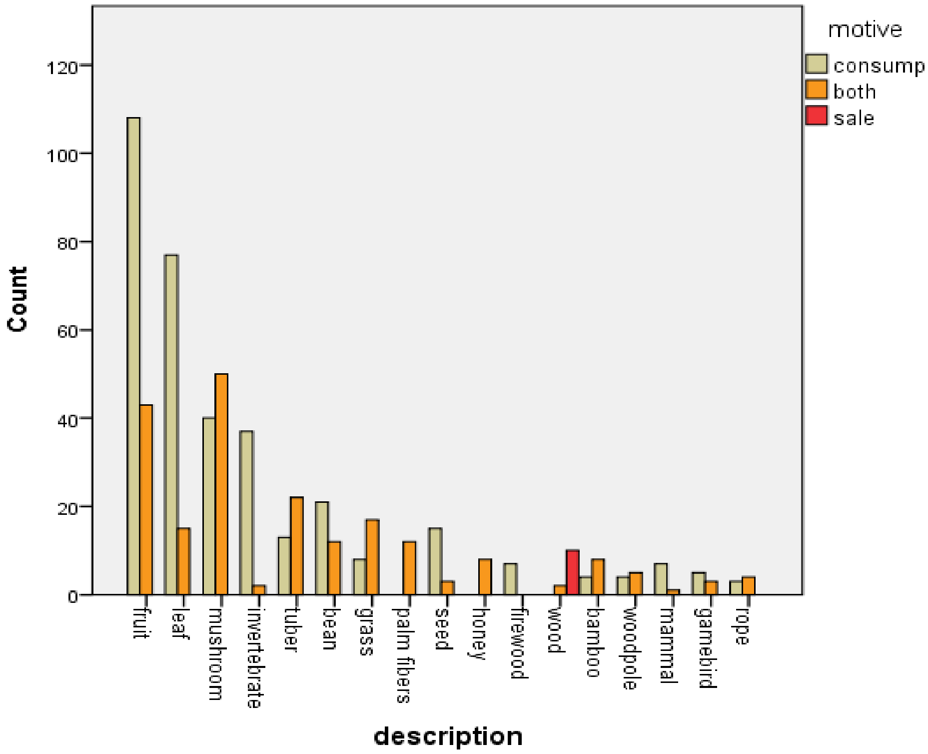

Figure 28. Frequency of responses for the motive of collection of different forest resources per type, from semi-structured interviews: 1- for household consumption; 2-for both household consumption and sale; 3-for sale).

3.5.2. Perceptions of climate change and main hazards identified

The five sampled communities stated that climatic changes have been felt in the last 20 years. Most respondents from the interviews (57.2%) reported that those changes have been more evident in the last 2 to 4 years, while in the discussion groups 33% of the participants referred they have been evident for the last 10 years. Climate change was in all cases related to modifications in precipitation frequency and intensity. Napala community indicated drought problems, while all other communities suggested infrequent but very abundant rain.

Excessive rains were associated with soil erosion and excessive accumulation of water in the crops, causing the roots to rot. In Napala, lack of rain was also mentioned as causing soil erosion, particularly associated to the effect of uncontrolled burning. However, this was not observed during our field campaign up to 5 km north and south of the village centre.

It was consensual that climate influences the seasonal availability of most forest products, although just a few trends through time have been noticed. Participants stressed the potential influence of excessive rain in compromising the availability of a few important resources (mushrooms, some plants and trees). It was also stated that it might provoke wild fauna's death by water runoff cited as an event occurred before (in 2014) in the village of Nguia.

3.5.3. Identification of the main causes of ecosystem change, natural and anthropogenic

Overexploitation was referred in four of the communities (except Namitil) and particularly in Napala, as the main cause of ecosystem change and depletion of some of the forest resources. Napala presented the highest evidence of human pressure, derived from a combination of its demography (correspondent to a population increase of more than 300% in the last 10 years either from growth or migration) and its accessibility to/from medium-large commercial centres. Outsiders both from Macomia (inland) and from the coastal villages rely of forest resources from Napala, such as: construction materials (bamboo, wood poles, thatching grass, bark for ropes, rock), forest food resources, and wood and transformation materials, mainly for commercial purposes.

In Miegane, competition with elephants was appointed as the cause for reduced availability of five different resources: bamboo (for construction), two fruits, one bean and one tuber (for food). Of these, bamboo is of main concern for this community. This was the only community were the conflict with elephants was referred, but no serious or recent incidents were described. Namitil and Nguia, competition with monkeys for wild fruits was referred as the main cause for reduced abundance of four fruits species (two in Namitil and two in Nguia), but none particularly relevant for the household diet and/or economy.

Namitil indicated that forests are currently “further away” from the village than it was 10 years ago, the main reason being the opening of cultivation areas.

Napala community was the only one referring uncontrolled burning and deforestation as causes of the reduction in thatching grass. Most of people from all communities were not conscious of environmental issues or changes in the ecosystems.

3.5.4. Assessment of the existing capacities to deal with climate changes.

a) Conservation agriculture initiatives

All five communities have benefited in the last decade from economic and social development projects (Aga Khan, Helvetas and Kulima; Dambiro et al. 2011) such as agriculture and market access. Some of these interventions focused on conservation agriculture technology, i.e. planting in lines, mulching, agro-forestry systems, optimization of water availability, introduction of improved crop varieties (maize–matuba; mapira-macia) and the establishment of demonstration fields (CDRs) (Mondlane Jr., 2010). The capacity built with these projects was present in all discussion groups and in more than 90% of the interviewees, who have demonstrated the application of different methods and techniques to improve agricultural production but also to reduce the risk from climate changes, namely: consociation of different crops (in average 4, in the sample); rotation of cultures to optimize water availability; use of a support crops (in community sampled mostly sweet potatoes and beans), to backup for main crop failure; creation of reserves of food and agricultural inputs (from clay pots to adobe barns, in practically all households sampled).

b) Alternative activities

A third of the respondents (30.6%) have undertaken a secondary economic activity in the last 10 years to increase family income. Particularly in Miegane, most of the interviewees had recently added a secondary activity. In this community, most of the respondents started to produce mats and house tools from vegetal fibres (55.5%), but there were also two people who had recently started to sell timber (22.2%). Miegane is the most remote village, located in one of the most well preserved miombo forests of QNP. There are a considerable number of inhabitants in the village, which consider the *Taratibo* conservation area as an obstacle to livelihoods improvement since the local inhabitants are not involved in forest resources management.

c) Communities' organization and institutions

Napala community demonstrated interest to organize their economic activities, through the constitution of local associations for the exploitation, transformation and commercialization of forest resources such as: wood, beekeeping and honey production. Previous capacity was already built locally and the community stressed the need for training and the establishment a sustainable forest management concession area. Napala's leader and residents stressed that this kind of organization is important to overcome the pressure from outsiders.

In contrast and despite its location along the main road, Nguia community did not show any kind of organizational initiatives. Most of the adaptation strategies, namely regarding agriculture or resource use are in general carried out individually. The leader of the community provided this information, but did not refer any specific reasons for the lack of organization.

As for Nanduli and Namitil, these communities felt somehow isolated – poor access and no transportation available make these two communities away from main markets and infrastructures, and the effect of overexploitation of resources was not pointed out. In Nanduli, the problem with the Mareja *conservation area* was also mentioned, especially regarding the restriction on subsistence hunting.

d) Gender and social vulnerability

Both gender in the family share the responsibility of agricultural activities and the collection of forest resources. However, there is some variation as women focus mainly on the collection of food resources (as fruits, leafs, tubers) and firewood, as men concentrate more efforts in collecting construction materials and hunting vertebrates, for example. The two groups had a common perception about the availability of resources and approximately the same numbers of important plants, animals or other groups were cited by both men and women. Women were also generally aware of conservation agriculture techniques.

Women are also responsible for the domestic work and care of children. With lower average literacy than men (up to grade 2,28 in women and 3,63 in men), several female interviewees have admitted to leave school when they married or got pregnant. Most women did not speak Portuguese but only Macua, contrarily to men who generally could communicate in Portuguese. The female respondents in Napala demonstrated a great interest on the establishment of an adult education classroom in the community, with particular focus in women's education. Both the overload of domestic responsibilities and the low literacy are limiting factors for the diversification of economic activities within the household, but also to understand and manage climate-related information.

3.6. Vulnerability analysis

Our analysis revealed that the 5 studied communities are in general exposed to droughts, floods and storms, but Napala, Miegane and Nguia have the highest vulnerability for different reasons. Napala located nearer to the coast, is drier thus suffering from increased high speed winds and fires; it is also located close to a commercial centres (Macomia and the coast); Nguia located on the main road, has a moderately degraded woodland, and community organization to face climatic risks is still developing (associations, natural resources management committees); and Miegane is located in a very remote area, with relatively well conserved woodland but with high population density, medium fire frequency and less access to alternative livelihood systems. Namitil and Nanduli presented medium risk to climate change, given their location in a well-conserved woodland, low fire risk and relatively good community organization capacity. The vulnerability matrix developed for this study is presented in Table 10.

Table 10. Vulnerability Analysis Matrix developed for 5 communities in the QNP.

Communities	Risk/disaster	Affected assets	Strategies used to reduce risks/hazards	Community actions and perceptions (past and future)	Exposure and Vulnerability (low/medium/high)	Opportunities for intervention
Napala	Fires	Infrastructures; Farms; Thatching grass			High	Awareness campaigns; firebreaks around farms and infrastructures.
	Droughts	Honey production; Mushrooms and some forest fruits and leafs; Farming products; Water for domestic uses	Drought resistant crops; Planting in lowland areas (rice); Storing of agricultural products, but yields are low.	Rain patterns reported to be less frequent and scarce	High	Water holes and/or pumps; dams and/or rainfall water harvest systems; Supply of seeds of improved crop varieties and/or vegetables.
	Storms	Infrastructures; Crop damage;	None	Reported an increase of the frequency and intensity of storms with strong winds.	Medium	Wind-breaks around farms and infrastructures
Nanduli, Namitil	Droughts	Mushrooms and honey; Farming products; Water for domestic uses	Drought resistant crops; Planting in lowland areas (rice); Storing of agricultural products.		Medium	Water holes and/or pumps; dams and/or rainfall water harvest systems

	Floods	Some forest herbs and mushrooms; Crop damage; Access roads and Infrastructures; Soil erosion	Planting in highland areas; Crop diversification; Vegetable cultivation after the rains	Rain patterns reported to be irregular	Medium	Water retention systems to protect farms; Supply of seeds of vegetables and sweet potatoes
	Storms	Infrastructures; Crop damage;	none	Reported an increase of the frequency and intensity of storms with strong winds.	High	Wind-breaks around farms and infrastructures; Improved construction of school and communal buildings
Nguia and Miegane	Floods	wild animals, some herbs and mushrooms; Crop damage; Access roads and Infrastructures; Soil erosion	Planting in highland areas; Crop diversification; Vegetable cultivation after the rains	Rain patterns reported to be irregular and intense	High	Water retention or drainage systems to protect farms and infrastructures; Supply of seeds of vegetables and sweet potatoes
	Storms	Infrastructures; Crop damage;	none	Reported an increase of the frequency and intensity of storms with strong winds.	High	Wind-breaks around farms and infrastructures; Improved construction of school and communal buildings

3.7. Ecosystem modelling

3.7.1. Meteorological characteristic

The daily meteorological data estimated by MT–CLIM for the study site showed that during the period of 1952 to 2015, annual precipitation ranged from 506.5 mm to 1720.6 mm, with an average of 992.1±40.7 mm (±SE). Annual average temperature was 21.7℃ ±0.13 (±SE). The large SE values indicates great inter-annual climatic variations (Precip., CV = 28.72 %; Temp., CV = 2.98 %). There was a clear periodic change in temperature and precipitation, but overall no major trends were observed during the period. Between 1964 and 1976 there was an overall increase in temperature and a decreased in precipitation (*r = -0.34, P =0.037*) but both fell afterwards (Figure 29).

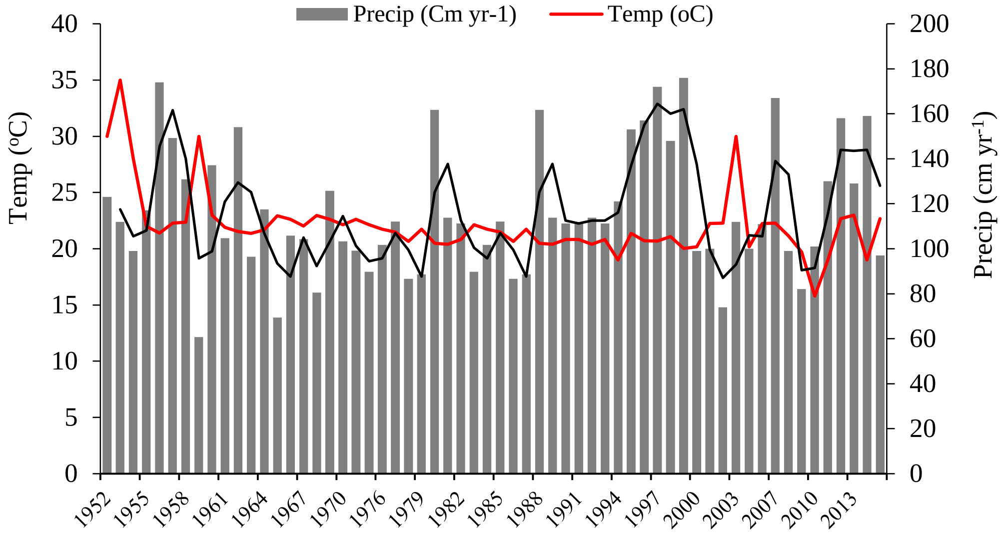

Figure 29. Trend of meteorological data estimated by MT–CLIM for the study site from 39 years (1952 to 2015).

3.7.2. Relationships between ecosystem productivity and climate

Our findings show that during the 1952-2015 period, the mean annual NPP estimated was 270.2 gC/m^2/yr±8.93 (±*SE*) with a range from 174.2 to 382.0 gC/m^2/yr for the years 1980 and 1967, respectively.

The CO_2 levels during the period 1952 to 2015 ranged between 312 and 391 μmol/mol with average 346.4±44.72 μmol/mol. Figure 30 shows that there is a strong negative correlation between CO_2 and NPP (*r = -0.66, P =0.0005*). The Leaf Area Index (LAI) had average of 1.17 m^2/m^2±0.04 (±SE) and a range from 0.82 to 1.64 m^2/m^2. These parameters are the fundamental determinants of ecosystem processes of carbon and determine the timing and duration of a photosynthetically active canopy, influencing the magnitude of carbon and water fluxes throughout the plant-growing season (Running et al., 1987). The variation of NPP and LAI with precipitation, temperature and CO_2 indicates the ecosystem's response to climatic changes (Figure 31).

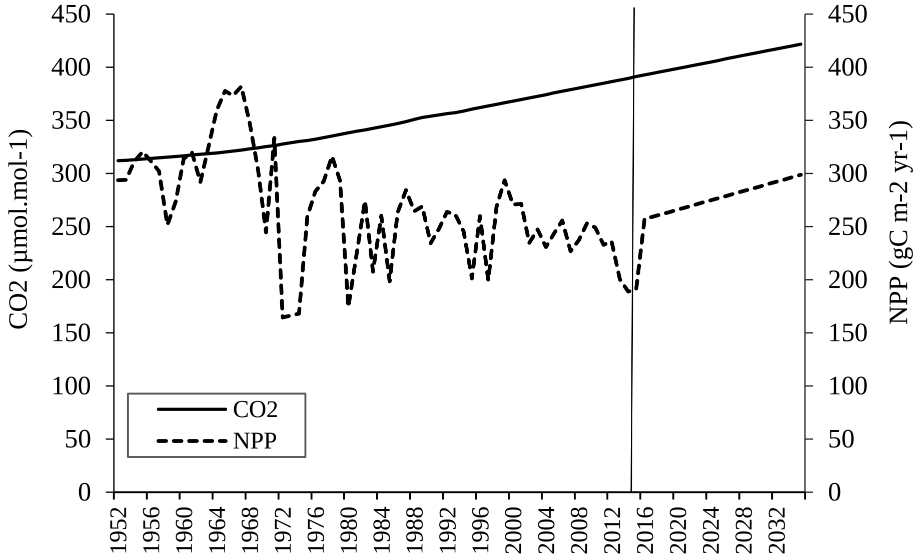

Figure 30. Simulation of CO2 and NPP between 1952 to 2015 and projected trend for the next 20 years (2015 to 2035 years).

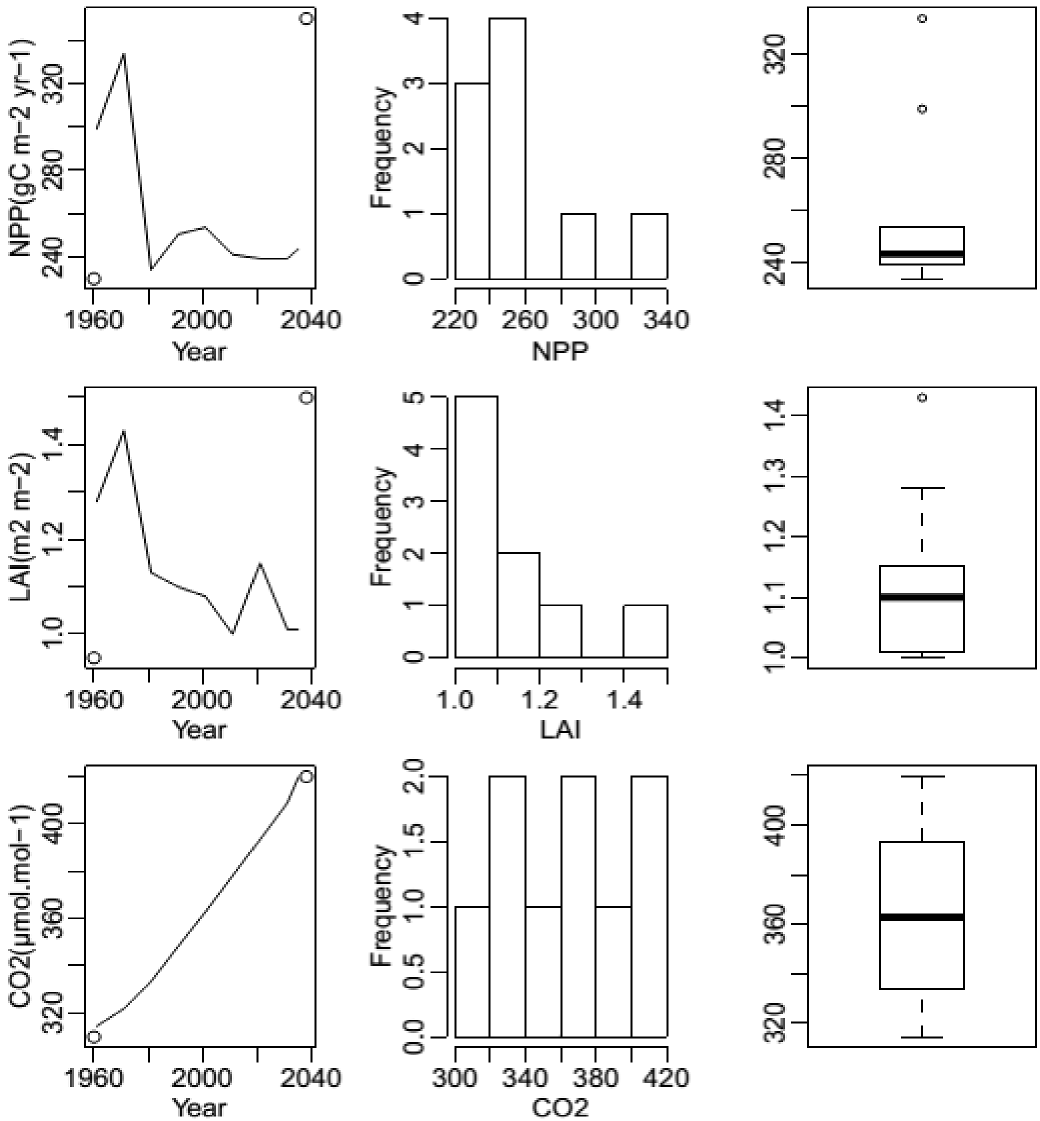

Figure 31. Simulation and Histograms of each parameter and their boxplot are shown on right panel 1960 a 2040 from Quirimbas National Park. NPP: Net Primary Production (gC m^{-2} yr^{-1}), LAI: Leaf Area Index (m^{2} m^{-2}), CO_2 atmospheric CO_2 (µmol.mol^{-1}).

4. Discussion

The results from our study reveal that despite the land cover changes observed in the last 22 years the miombo woodlands in the QNP are still the dominating land cover type (38%). Conversion of land to agriculture was the main cause of woodland loss (25%) in the last 22 years. However, areas converted to agriculture are mostly located outside of protected zones, but the southern portion of Block A shows a major spot of woodland loss during the study period. Several other factors have been pointed out as the main causes of woodland degradation in the park such as: fires and (illegal) logging (GRNB, 2010), but these were not detected at the Landsat image resolution of 30-m.

The fire regime (extension, intensity, density and frequency) has an intra-annual variation according to the annual weather variations and, as expected are more expressive during the late dry season. Inter-annual variations indicate a cyclic trend, with years of high fire density followed by years of low fire occurrence. Ribeiro (2007) and Cangela (2014) observed a similar pattern in the Niassa National Reserve. The authors indicate that this pattern is expected and it results from intermittent periods of high and low accumulation of fuel-load in the ecosystem. Fire intensity is in general low compared with other studies in the miombo (intensity=45 Kj; Ishoku et al., 2008).

Fire frequency for the majority of the park is low (1 to 3 times in 14 years). However, the western and northern sides burned more frequently (every 2 years in the west and annually in the north). Fire frequency is usually an element of concern in miombo as it may affect woodland structure and composition by killing young sapling and seeds of certain species (Ribeiro et al., 2008). However, according to Frost (1996) and Chidumayo (1997) a fire frequency of 2-3 years is necessary to allow regeneration of miombo tree species and maintain the ecosystem in equilibrium. Consequently, our results reveal that fire is not a major issue from the ecological point of view. However, at some places (northern portion of block C and surroundings) annual fire frequency may affect the ecosystem and the availability of resources to local communities. In fact, our socio-economic surveys in Napala (located in block C) indicated fire as one of the main factors affecting resources availability.

Although the current fire regime is not a major concern, it may change in the future given the predicted changes in climate variables for the area (about 15% more in rainfall and an increase of up to 3^{o}C in temperature in 30-40 years and longer dry seasons; INGC, 2009). These will probably cause higher fuel accumulation, which may result in increased late dry season fire intensity and extent and consequently modifications of ecosystem composition and structure may occur. Increased fire intensity and extension may exacerbate the effect of drought on food availability, thereby increasing the vulnerability of both human and wildlife, especially megaherbivores with slow demographic responses to changing resources and conditions (Owen-Smith 1988).

The miombo woodland biodiversity and stock (volume and biomass) in the QNP are characteristic of the woodlands in the region (Frost, 1996, Chidumayo, 1997, Ribeiro et al., 2013), with ecological dominance of a few typical tree species

(*Julbernardia globiflora, Brachystegia boehmmii, B. spiciformis, Diplorynchus condylocarpon, Pseudolachnostylis maprouneifolia,* among others*)*, medium timber stock (tree biomass =1.16-1.46 Mg/ha and mean volume= 12-20 m^3/ha) represented by highly valuable timber species (*P. angolensis, D. melanoxylon, P. myrtifolia and M. stuhlmannii*) (Sitoe, 1996, Ribeiro, 2013). Blocks A and B have a more intact miombo as indicated by the approximate inverted J-shaped dbh distribution. In contrast, around the Nguia village (CDZ) the miombo reveals patterns of degradation such as an irregular diametric distribution and the ecological dominance of *D. cinerea* (an indicator of forest degradation). Block C is a dry miombo with coastal influence and as such species of the genera *Acacia* and *Albizia* are abundant. Here, the woodlands do not show major signs of ecosystem disturbance.

Tree species composition and structure do not present major modifications according to the proximity to the villages, but some signs of ecosystem intervention were found. Closer to the villages (1 km) the ecosystem is more diverse and with higher abundance of small trees (5-10 cm dbh; height < 5 m) revealing a woodland in secondary succession, while far from the villages (3km and 5km) large trees are found more abundantly and the woodland is denser and taller (15-20 m). We reported more evidences of mammal occurrence in areas far from villages, where the habitat is less disturbed by human activities, except for species that tolerate disturbance such as common duiker (Skinner and Chimimba, 2005), which benefits from the increase in habitat heterogeneity associated with disturbances closer to the villages. This finding corroborates the results from the aerial wildlife census that covered a larger proportion of the park (Craig, 2013).

Our biodiversity assessments indicate that the miombo woodlands in QNP have a relatively good capacity to provide services to local communities. In fact, flora and fauna species that provide resources to local communities (fruits, roots, tubers, leaves, fibre, etc.) are well represented in the ecosystem (at all distances from the villages) as mushrooms (one of the main nutritional resources) are. Additionally, the socio-economic surveys revealed that miombo is still a major contributor to the livelihoods of people in the park and there is a general feeling that the resources from the woodlands are still enough to fulfil people’s requirements (nutrition, health, shelter, etc.). Resources availability changes throughout the year but in general there are always different types of resources available. Accessibility to resources is also good as most of the residents find important resources within 2 km from the main villages. Most of the resources are used for subsistence, but villages with higher accessibility (Napala and Nguia) have shifted to commercial activities (selling of forest resources) in the last 5 years. Recall that in these villages the status of the miombo woodlands is less well conserved.

Our simulation revealed that the NPP is within the range of observations by Mbanze (2010) for the same type of ecosystem in Niassa National Reserve (335.53 to 448.92 gCm^2/yr), but are higher than the range for tropical savanna (100 to 120 gCm^2/yr) (Grace et al., 2006). The LAI found in this study is higher than the one found by Woollen et al. (2012) in miombo woodlands of central Mozambique [0.8 $m^2/m^2 \pm 0.1$ ($\pm$ SE)]. The NPP is the balance between the quantity of carbon absorbed (which is used for the production of above and belowground biomass) and the CO_2 emitted from respiration, by the vegetation (Smith et al., 2010) while LAI provides information about the capacity for NPP. Both reveal that NPP decreased significantly in the last 60 years, but the values are still within the range for the ecosystem, revealing that the woodlands continue to be a sink of carbon. The predictions for the next 40 years indicate that with increased precipitation, temperature and CO_2 there will be a slight increase in the ecossystem's NPP and LAI, but they will not reach the levels of the year 1952.

The modelling results should be interpreted and used with caution for several reasons. The meteorological data used, was based on general projections from the INGC (2009) , while the model requires site specific climatic information. Also, high precipitation variability and increased temperature may change the water use efficiency, decrease soil moisture and enhance plant respiration thus, reducing plant capacity to thrive in changing climates (Bond, 2008). Those issues are not accounted for in the model. Finally, NPP can be reduced over time as a result of increased anthropogenic activities, changes in the fire regime, pests and/or herbivory all derived from climatic changes (Smith et al., 2010). According to the vegetation map (Figure 5), miombo woodlands are quite stable in the park, but some loss was observed and is expected to continue (or increase) in the next 20 years, due to population growth and improved accessibility.

The ongoing development of the oil and gas industry in the Rovuma Landscape will result in the development of social and economic infrastructures (e.g. access roads), increase in human population density, increase in the rate of conversion of natural habitats into cultivated areas, uncontrolled fires and the illegal harvest of natural resources. The consequence may be the loss of connectivity in the landscape, which will reduce the resilience of the ecosystem to disturbances and exacerbate the effects of climate change on biodiversity.

The use of space by wildlife is driven by the requirements for resources (forage, water and social interactions) and security from predators (including humans) and extreme weather events (Owen-Smith, 2002). Wild animals adapt behaviorally to climate change-related changes in habitat by increasing movements and the extent of the home range used in search for resources that become progressively scarce with the progress of the dry season (Owen-Smith 2013) or by concentrating foraging in key resource areas (Scoones, 1995). However, this adaptation strategy could be hampered by the conversion of wildlife natural habitats, including key resource areas (wildlife corridors, river banks, wetlands and *dambos*) into agricultural land associated with the increase of human population in the park and/or by the loss of ecosystem capacity to provide habitat and resources. Elephants are a keystone species in miombo woodlands, shaping vegetation structure and composition, and hence the habitat of other species. Therefore, in the long term, the reduction of elephant density caused by high poaching pressure will change the diversity, abundance and distribution of fauna and flora species in the miombo woodland, which may threaten the feasibility of eco-tourism activities and other ecosystem goods and services.

There is an overall agreement that in the last 10 years the local communities in the park have experienced erratic rains with short periods of too much rain and long dry periods. This situation has interfered with forest resources either by damaging and draining them during floods or reduced amounts during long dry periods. Fires were only reported in Napala. From the point of view of local communities, three main concerns are associated with the climate phenomena: damage of houses and other infrastructures, failure in crop production and decreased road quality. Recent extreme weather events, particularly strong and irregular rains, had inevitable consequences in terms of human wellbeing, including potential famine due to lack of agricultural production and infrastructure destruction.

Despite some demonstrated capacities to deal with climate change, especially in conservation agriculture, local communities and individuals have serious concerns about future weather events and their repercussion for livelihoods. In general people feel that lack of income diversification including non-agricultural livelihoods strategies, is a major issue. Particularly in communities with a demonstrated conflict with wildlife (Miegane and Nanduli), and where the demographic pressure tends to push towards an increase and resource diversification, tailored adaptation strategies should be considered. In the communities where the process of diversification is already in course (as in Napala and, less intensively, in Nguia), mostly resulting from an easy access to and from outside markets, the promotion of resources use zonation and community management is a priority action to promote sustainable resource use and trade. In villages such as Namitil, with a difficult access but a relatively small population, forest resources provide obvious support in the case of climate stress and poor agriculture production, but overall exploitation seems sustained.

Finally, the predicted changes in ecosystem productivity may affect human capacity to cope with the effects of climate change especially if the diversification of resources is reduced. This will be aggravated by the fact that people rely on reduced alternatives to forest resources and commercial opportunities are scarce. However, the fact that they are inside a conservation area provides an opportunity to create capacities and alternatives to the communities such as: engagement in tourism activities, promotion of conservation agriculture, creation and capacity building for natural resources management and patrolling.

5. Final considerations

5.1. Conclusions

This study provides an important insight in the current status of the miombo woodlands in the Quirimbas National Park, their capacity to provide resources to local communities, the role of fire and human drivers and the potential biomass trend in response to climate changes. In summary our conclusions are:

- The miombo woodlands occupy 38% of the QNP surface and have been relatively well maintained over the years. However, a 25% loss of total miombo area was observed. Thus close monitoring and management actions must be implemented (see section 5.3).
- The miombo in QNP can be considered in a relatively good state of conservation as indicated by flora and fauna species composition, diversity, diametric distribution and volume and, biomass stocks. Blocks A and B are better stocked in terms of diversity, volume and biomass than the other park zones. These have potential for engaging in REDD+ projects.
- Local people rely heavily on the woodlands all year round, especially during the dry season when agriculture is limited by weather conditions. The main woodland resources are: mushroom, wild fruits, honey and construction materials including thatch grass. Resources are mainly used for subsistence, but commercialization has become important in villages with better accessibility to roads and markets (Nguia and Napala).
- Evidences of climate change were observed in the park and these are mainly modifications of the rainfall pattern (short periods of heavy rains followed by long dry periods). The main reported effects were: loss of crops, damage and loss of infrastructures, fauna mortality, among others.
- Fire frequency and intensity in the area are not particularly high in the park. As such fires are not likely to be a major driver of forest degradation. However, areas of concern are the western and northern regions of the park. For this area, monitoring activities should be considered as a priority.
- Changes in fire regime related to climate changes are expected and already observed in some portions of the park (Napala).
- Ecosystem primary production is expected to have a slight increase with changes in precipitation and temperature in the next 30-40 years. This trend must be carefully monitored over time since our predictions present some level of inaccuracy.
- Changes in primary production may change availability of forest resources to local people but also in habitat for wildlife. This represents a matter of further follow up.
- Local communities investigated in this study have some level of organization and capacity to adapt to climate change. Conservation agriculture techniques are well spread, livelihood diversification was observed in Napala and Nguia, but it is

related to better accessibility to roads and markets. There is, however, a need to capacitate communities in forest management practices and engage them in tourism related activities.

5.2. Knowledge gaps and research priorities

Our study indicates that the miombo woodlands in QNP may continue to be a carbon sink in the next 30-40 years, but the trend is still uncertain and needs to be further monitored. Carbon fluxes are determined by factors such as: soil organic carbon (SOC), nutrient cycling, soil structural stability and water holding capacity, each of which contributing to supporting, provisioning and regulating services, such as climate regulation, food and timber production. Land use and management systems further influence significantly those processes and thus ecosystem's capacity to store carbon. These are particularly important to understand in the context of the QNP, given that human growth and consequent pressure over the woodlands is expected. Thus developing strategies to mitigate the effects of climate change and human impact such as the REDD+ mechanism are important. The following is a summary of knowledge gaps for the miombo woodlands in QNP (and in the region) that should be considered before engaging in REDD+ projects:

- **Below ground carbon stocks**: influencing factors, monitoring methods, effects of drivers and contribution to carbon dynamics.
- **Above ground carbon stocks**: spatial and component (tree, shrubs, grass, litter, soil, etc.) variability, contribution of miombo regrowth to carbon stocks, monitoring methods, human and climate drivers, link with other ecosystem services.
- **Fires**: GHG emissions, effects on ecosystem composition and structure, management needs and capacities.
- **Payment for ecosystem services**: links between carbon, ecosystem services, drivers, poverty-environment linkages, economic value of specific ecosystem services (mushrooms, wild fruits, grasses).
- **Species populations**: There are huge gaps of knowledge about the effects of climate changes on species populations and this is important from the point of view of changes in provisioning services from miombo. For instance, De Cauwer et al. (2014) indicate that climate change may decrease *Pterocarpus angolensis* populations due to reduced rainfall, lower minimum winter temperature and temperature seasonality. There are also evidences in the region that a change in precipitation variability across the year and increased temperatures may change the phenology (flowering and fruiting) of some miombo species.

Additionally the following gaps are important from the point of view of climate changes and its effect on miombo:

- Progress has been made in the use of Global Circulation Models (GCM) to predict changes in climate variables over large spatial scale. However, there are no reliable predictions of change in climate variables at local spatial scale, where the impacts of climate change on biodiversity should be mitigated.
- Limited research and monitoring of key biodiversity components that would generate data and knowledge to support adaptive management decisions to address the impact of the changing climate on biodiversity.

- Lack of long term data on seasonal movements and space use patterns by large mammals, to detect predicted changes in the distribution of species in the landscape.
- Difficulties in disentangling the impacts of climate change on miombo biodiversity from the impact of direct causes of biodiversity loss such as land cover change and overexploitation of natural resources.

Based on the knowledge gaps identified above the following are future research priorities for the miombo woodlands in QNP:

- Establish long-term monitoring plots to address changes in woodlands composition and structure.
- Assess the ecological condition and sustainable levels of collection for some ecosystem services: mushroom, wild fruits, honey and thatch grass.
- Determine the economic value of particular ecosystem services above referred.
- Assess the responses of particular species (timber, food, construction) to climate and human drivers.
- Study the link between climate and human drivers on ecosystems.

5.3. Policy-oriented Recommendations

Based on our results we recommend the following actions:

- Blocks A and B should be considered as pilot areas for developing REDD+ projects. In developing REDD+ the identified knowledge gaps and research questions must be taken into consideration. Also, a detailed carbon inventory must be carried out beforehand.
- Support sustainable livelihoods in the protection zones, buffer zone and in the corridor, to reduce habitat conversion to cultivation, encroachment of human in wildlife key resource areas and the reduction of uncontrolled fires. This will help maintain habitat suitability in wildlife dispersal areas, which will be increasingly important to sustain wildlife populations under climate change in the wider Rovuma Landscape.
- Monitor changes in the distribution of density of large mammals in relation to natural (e.g. water distribution) and anthropogenic (e.g. human settlements and land cover change) factors through aerial surveys, as a basis for identifying priorities areas of the park for the allocation of management resources (including patrolling effort).
- It is urgent to define a global strategy for the QNP and resident communities to minimize the impact of climate phenomena and reinforce the local capacities to adapt to potential changes. This must engage local institutions (governmental and non-governmental) in the process of gathering data, analysing climate risks and planning for appropriate actions, as well as establishing mechanisms for communication of climate information within the communities. Further training in climate-resilient agricultural practices and support for income diversification are priority areas to work with the communities in order to improve their resilience and adaptation to climate change.
- As opportunities for intervention, interviewees refereed the donation of improved seeds, particularly of second-season ones (sweet potatoes and

beans) and green vegetables, to ensure diet requirements in lean periods caused by floods or droughts; regular road maintenance and construction or rehabilitation of communal infrastructures, as schools, health centre and mosques.

- Building knowledge and skills on adaptation strategies specifically with women (e.g. food preservation and valuation of local products), and promote the access to continuous education for the most vulnerable groups – women and children - is essential to increase individual capacity for adaptation, especially amongst most vulnerable groups in society.

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Annexes

Annex I- Guiding questions to the focus groups

Annex II - semi-structured interview

Annex III- BIOM-BGC parameter used in this study

Annex IV- matrix error

Annex V – spatial distribution of fires

Annex VI - forest resources named by respondents in the sampled communities, their description and uses.

ANNEX I. Guiding questions to the focus groups

1. Enumerar e caracterizar os recursos florestais utilizados pela comunidade

Produtos florestais explorados	**Descrição da exploração / utilização** (eg. Alimentação, combustível, medicina, etc)	**Motivo da exploração** Consumo/ Venda/ Ambos	**Ordenar por importância** (considerar empates?)	**Onde se encontram** (eg. Perto machambas, perto rio, floresta fechada...)	**Distância aproximada** (mins a pé)	**Sazonalidade** tem estação? (sim/ não/ não sabem) **Qual?**	**Dificuldade em encontrar/ apanhar** (fácil/ mais ou menos/ difícil/ muito difícil)	**Variação nos últimos dez anos** (tem menos/ tem o mesmo/ tem mais/ não sabe)	**Ordenar por dificuldade em encontrar / apanhar**	**Outras observações**

2. Enumerar riscos climáticos ("problemas causados pelas mudanças do tempo") que podem afectar os recursos e a comunidade
3. Construir uma matriz de vulnerabilidade – usar uma escala de 0 a 4?

	2. Enumerar Riscos ("Problemas") que podem afectar o seu uso				
1. Enumerar Recursos/ Produtos florestais	Atribuir uma classificação para o impacto do problema identificado no recurso em causa (0 – nulo a 4 – elevado)				

4. O que acham que vai acontecer se os riscos climáticos (mudanças do tempo observadas e identificadas como problema) continuarem a acontecer? (a) Na próxima estação; (b) Quando as crianças que nascem agora entrarem na escola; c) quando essas crianças já tiverem filhos

5. O que se pode fazer para proteger os recursos e as populações? Os indivíduos; b) a comunidade; c) o PNQ

ANNEX II. Semi-structured Interview

Ficha geral de identificação e caracterização da comunidade

Março 2015

Comunidade: Prot / PNQ/ ZTampão	**Distrito:**	**Zona PNQ:** Blocos
Numero total de habitantes: **Crianças:**	**Agregados:** **Homens:**	**Mulheres:**

Entrevistado: **Data:**
Entrevistador:

1. Quais as principais referências históricas da comunidade:

2. Acessibilidade e infra-estruturas

Recurso	**Tem/Não tem/Às vezes**	**A disponibilidade varia?**	**Como / Onde?**	**Distância**
Água				
Energia				
Machambas em blocos				

3. Uso de combustível a nível doméstico

Tipo de combustível	**Importância** (pouco/médio /muito/essencial)	**Como abastecem?** (Apanha/ Compra/ Troca/ Outro)	**Onde/como? (distância e custo)**	**Mais ou menos importante do que no passado? Porquê?**
Lenha				
Carvão				
Petróleo				

4. Principais actividades económicas/de subsistência

Actividade	**Descrição**	**Número**	**Razão:**	**Contribuição**

	(tipo de culturas, espécies de animais, descrição da actividade)	**aproximado de pessoas que praticam**	**Consumo/ Vender/ Ambos**	**económica para a família** (fraca, suficiente, boa, muito boa, não sabe/não responde)
Agricultura				
Criação de animais				
Caça				
Pesca				
Carvão				
Administração e Educação				
Transformação				
Serviços				
Comércio				

5. Nota-se alguma mudança das principais actividades económicas na comunidade? (Eg. Surgiram ou aumentaram novas actividades, como apicultura, extracção de carvão, caça, outras?) **___sim ___não __não sabe**

Quais?
____

Desde quando?
____

Porquê?
____

6. Principais recursos florestais explorados

Recurso	**Uso doméstico / comercial / ambos**	**Disponibilidade** (tem pouco/ tem suficiente/ tem muito/ Não sabe)	**Variação no tempo** (diminuiu/ está na mesma/aumentou / Não sabe)	**Sazonalidade: tem época?** (sim/não - todo o ano/não sabe) **Qual?**	**Importância para as famílias** (pouco importante/ importante/

					muito importante/ essencial/ não sabe)

7. Nota-se alguma mudança no tipo e quantidade de produtos da floresta usados pela comunidade?

___**sim** ___**não** __**não sabe**

O que mudou?

____

Porquê?

____

Desde quando?

____

8. Há alguns produtos da floresta que sejam sagrados para a comunidade, ou que sejam usados só para ocasiões especiais?

___**sim** ___**não** __**não sabe**

Quais?

____

Onde estão?

____

Têm variado no tempo? **Há mais** ___ **o mesmo** ___ **menos** ___ **não sabe** ____
Porquê?

____

9. Sente que tem havido mudanças do tempo nos últimos anos? ___**sim** ___**não** __**não sabe**

Desde quando?

____

Quais?

____

____

10. Na comunidade, faz se alguma coisa para proteger das mudanças do tempo e outros riscos?

___**sim** ___**não** __**não sabe**

O quê? (Eg. Armazenamento de produtos, planeamento de culturas e actividades, outros)

____

11. Faz-se alguma coisa para melhorar as culturas ou tornar mais resistentes a mudanças do tempo e outros riscos, como pragas ou outros?

___**sim** ___**não** __**não sabe**

O Quê? ____

Cada pessoa sozinha ou a comunidades em conjunto? ____

Há algum apoio de fora? ___**sim** ___**não** __**não sabe**

Qual? ____

12. O que acha que pode acontecer à comunidade no futuro por causa das mudanças do tempo?
    a) Na próxima estação ____
    b) Quando as crianças que entram agora na escola ficarem adultas? ____
    c) Quando essas crianças já tiverem filhos na escola?

Muito obrigada pela disponibilidade

ANNEX II. Semi-structure interview

Entrevistas individuais

Março 2015

Comunidade:	**Data:**	**Entrevistador:**
Entrevistado:	**Idade:**	**Estado civil:**
Escolaridade:		
Numero filhos:	**Numero pessoas do agregado (família):**	

1. Há quanto tempo vive na comunidade? **Desde sempre____ ; Desde há ___anos**

   Porque veio para ca?

   ____

2. Quais são as actividades de rendimento da sua família (da mais importante à menos importante para a subsistência)?

Actividade	**Frequência** (todos os dias/várias vezes por semana/várias vezes por mês/de vez em quando)	**Número de pessoas da família que praticam (idade e sexo)**	**Subsistência/ Comercial/ Ambos**	**Contribuição para o rendimento da família** (fraca, suficiente, boa, muito boa, essencial, não sabe/não responde)

3. A família tem machamba própria? ___**sim** ___**não** __**não sabe**

   Fica isolada ou em bloco? Isolada____ em bloco _____
   A quê distância da casa (minutos)?

   ____

   Que culturas produzem?

   ____

   Têm havido algumas alterações no rendimento ao longo dos anos? ___**sim** ___**não**
   __**não sabe**
   Quais?____
   Guardam ou armazenam produtos da machamba? ___**sim** ___**não** __**não sabe**
   Onde?

   ____

4. Houve alguma mudança recente nas actividades de rendimento da família (começaram alguma actividade nova, deixaram outra que não dava mais rendimento, etc…)? ___**sim** ___**não** __**não sabe**

   Qual?

   ____

   Quando?____
   Porquê?____

5. Onde é que a família vai buscar água para a casa? ____

A que distância?____

Costuma haver falta? ___**sim** ___**não** __**não sabe**

Como fazem quando falta? ____

6. Que combustíveis utilizam na familia?

Tipo de combustível	**Frequência de uso** (todos os dias/várias vezes por semana/ várias vezes por mês/ de vez em quando)	**Como abastecem (**Apanha/ Compra/ Troca/ Outro)	**Onde/ como (distância e custo)**

7. Que produtos da floresta costumam apanhar para utilizar em casa?

Produto	**Motivo de uso**	**Consumo/ venda/ ambos**	**Frequência de uso** (todos os dias/ várias vezes por semana/ várias vezes por mês/ de vez em quando)	**Sazonalidade: tem época?** (sim/não - dá todo o ano/não sabe) **Qual?**	**Importância para a família** (pouco importante/ importante/ muito importante/ essencial/ não sabe)

8. Qual a disponibilidade dos produtos da floresta, e como tem mudado com o tempo?

Produto	**Disponibilidade** (tem pouco/ algum/ bastante/ muito)	**Localização** (tipo de floresta)	**Distância** (minutos)	**Variação** (dez anos) (tem menos/ o mesmo/ mais/ não sabe)	**Porquê variou?**

9. Sente que tem havido mudanças do tempo nos últimos anos? ___**sim** ___**não** __**não sabe**

Desde quando? ____

Quais? ____

10. Quais são os maiores problemas causados pelas mudanças do tempo? ____

A família tem feito alguma coisa para se proteger desses problemas? ___**sim** ___**não** __**não sabe**

O quê?____

11. O que acha que era preciso fazer para proteger a comunidade das mudanças do tempo? ____

Muito obrigada pela disponibilidade

ANNEX III. BIOME –BGC parameters used in this study

Parameters	Value	Unit	Source
Latitude	12.04	Celsius degrees	Google earth
Longitude	39.9	Celsius degrees	Google earth
Elevation	200	m	Google earth
Isohyet	70	cm/year	Strabler & Strabler (2005)
Sand	77	%	Ribeiro et al. (2008)
Clay	10	%	Ribeiro et al. (2008)
Silt	13	%	Ribeiro et al. (2008)
Soil depth	300	cm	Campbell (1996)
FrMO	0.0065	1 per year	Ribeiro et al. (2008)
ALRFj	1.455	Proportion	Campbell (1996)
FPMA	0.0033	%	Ribeiro et al. (2008)

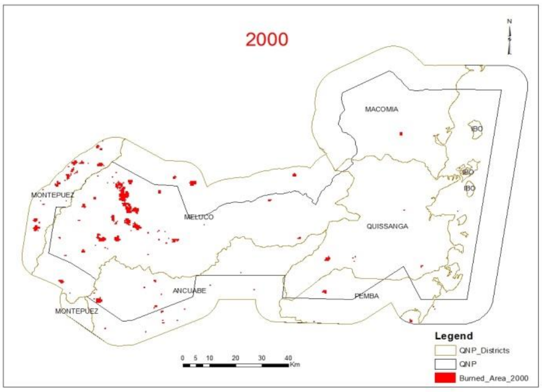
Ribeiro N. S, Shugart. H. Swap, Okin. 2008. Five-year Period of Fire Regime in the Miombo woodlands of Niassa Reserve, Mozambique, Chapter IV.

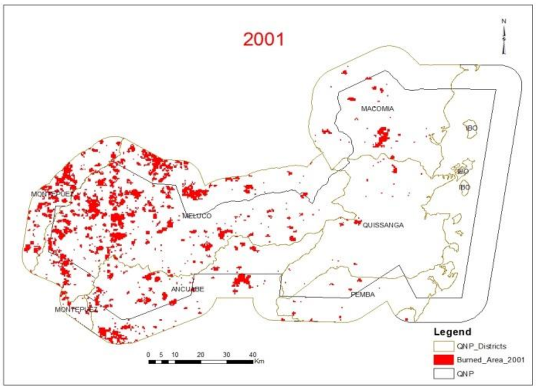
ANNEX IV. Error matrix for the supervised classification based on the maximum likelihood algorithm.

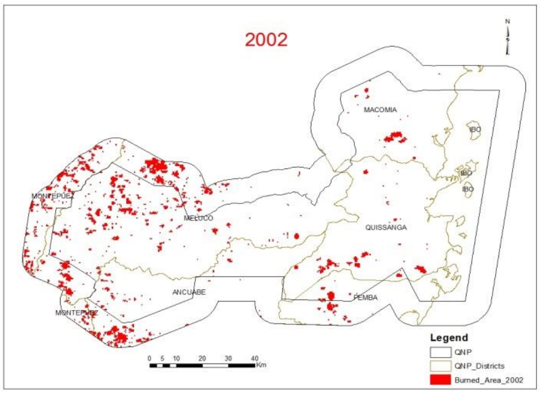
Classified Image	Control Point									
	Open Miombo W	Dense Miombo W	Agriculture/Settlements	Thickets	Open Woodland/Gras	Mangroves	Dense Mixed W	Water	Inselbergs/Miombo Velloziaze	Total
Open Miombo Woodland	22	1	0	0	0	0	0	0	0	23
Dense Miombo Woodland	5	18	0	1	0	1	0	0	0	25
Agriculture/Settlements	0	0	6	0	3	0	0	0	0	9
Thickets	0	0	0	7	1	0	1	0	0	9
Open Woodland/Grassland	2	2	1	0	26	0	0	0	0	31
Mangroves	0	0	0	1	0	2	0	0	0	3
Dense Mixed Woodland	0	0	0	0	3	0	10	0	0	13
Water	0	0	0	0	0	0	0	11	0	11
Inselbergs/Miombo Velloziaze	0	0	0	0	0	0	0	0	1	1
Total	29	21	7	9	33	3	11	11	1	125

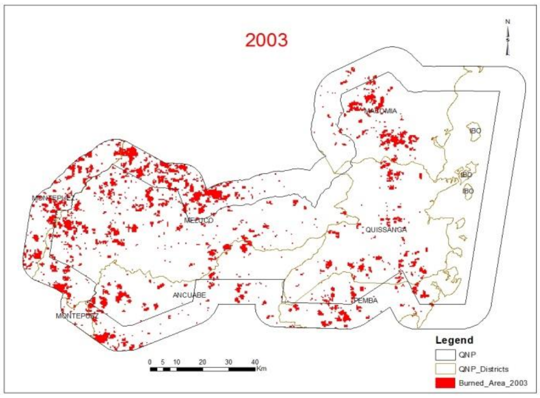
Overall accuracy (P_o): 82.40% **Overall Kappa Statistic (K): 78.83%**

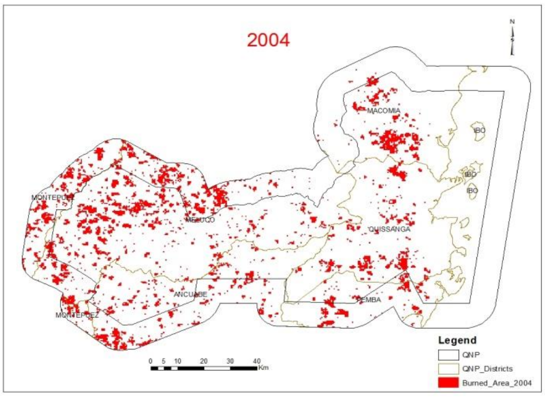
ANNEX V. Spatial Distribution of area burned from 2000-2014

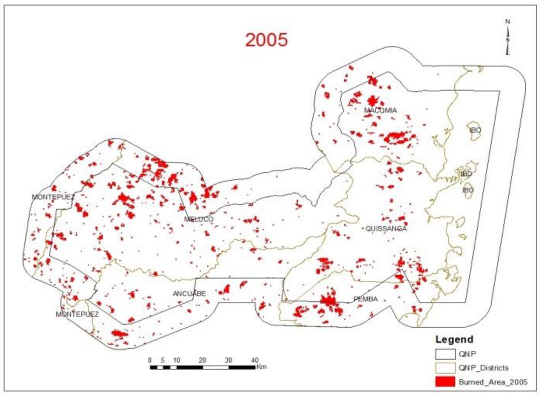


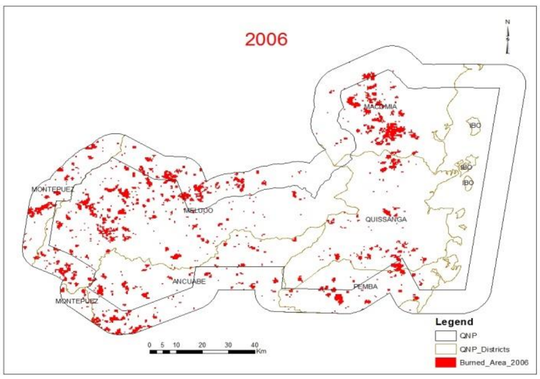


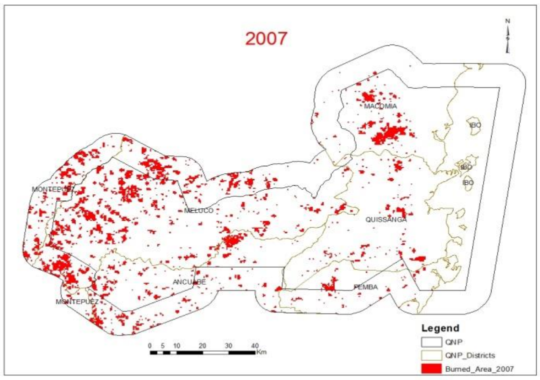


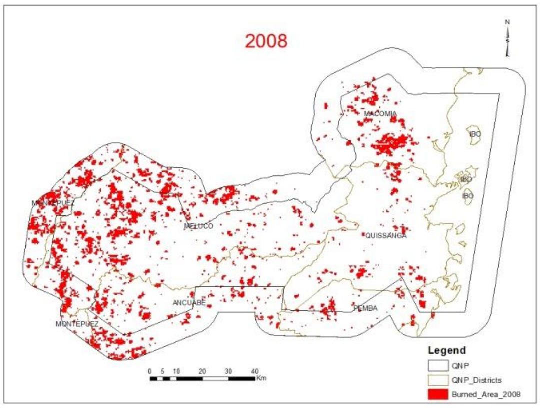











2008
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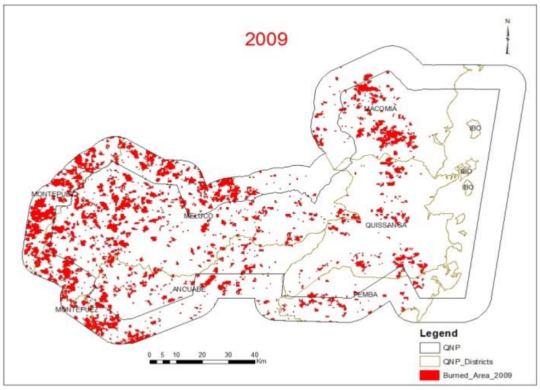
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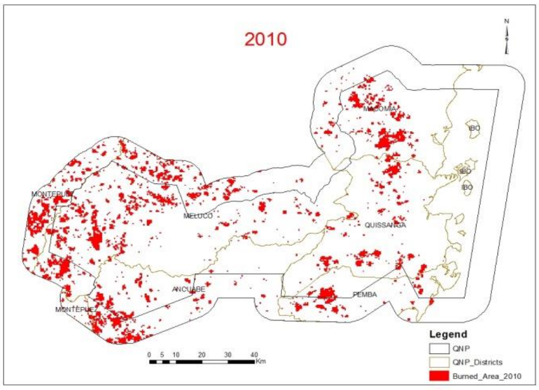
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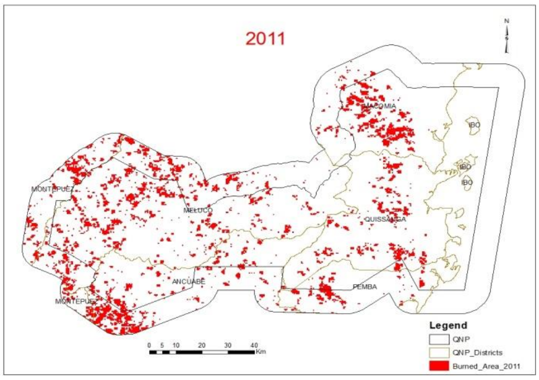
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Burned_Area_2011
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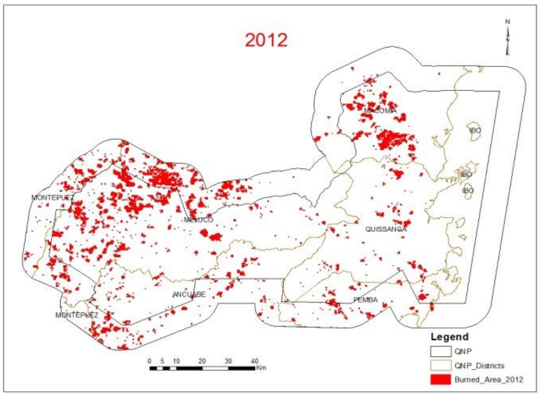
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Burned_Area_2012
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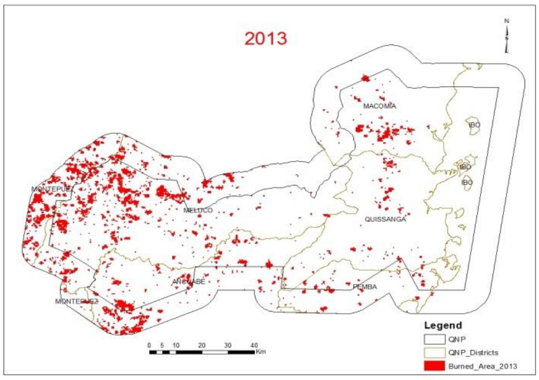
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Burned_Area_2013
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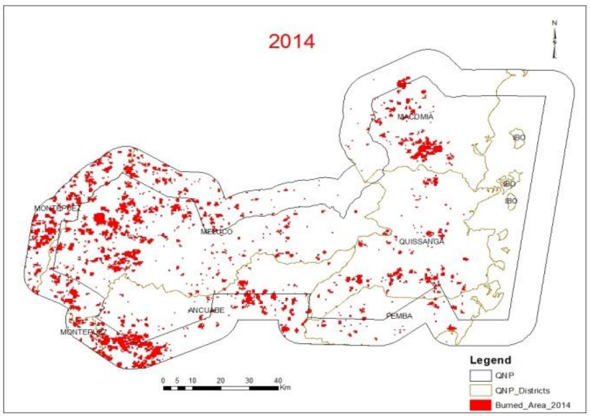
2014
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Burned_Area_2014
0 5 10 20 30 40 Km

ANNEX VI. List of the forest resources named by respondents in the sampled communities, their description and uses.

Local name	Type	Common or scientifiname	Use
PLANTS			
chanfuta	wood	chanfuta	construction/transformation
cinhenhé	tree	pau ferro	construction/transformation
cinti	leaves		food
djanpila	fruit		medicine
ekula	fruit		food
ferupe	fruit		food
icuti	fruit		food
ifunculi	leaves		food
ihaka	bean		food
ihevu	fruit		food
ihuru	fruit		food
ikakuata	fruit		food
ikirandji	tuber		food
ikojo	tuber		medicine
ikoko	seed	*Sclerocarya birrea*	food
ikunadji	fruit		food
ikuti	fruit		food
inbamia	leaves		food
inheué	bean		food
insauí	wood		construction/transformation
ioloko	bean		food
ipahka	seed		food
ipidji	fruit		food
iréte	fruit		food
Itahka	leaves		food
itarri	tuber		food
itema	fruit		food
itia	bean		food
itupi	fruit		food
iviu	tuber		food
kalompa	tuber		medicine
kivarelé	bark (rope)		construction
kolico	fruit		food
kudua	fruit		food
kuluko	fruit		food
kutukuro	fruit		food
macocuata	fruit		food
macuti	fruit		food
madjipi	tuber		food

malassi	tatch grass		construction
mankoko	medicine		medicine
manpiululu	fruit		food
marepe	fruit	*Sclerocarya birrea*	food
maróto	fruit		food
matope	fruit		food
mbila	wood	mbila	construction/transformation
mehtale	bamboo	bamboo	construction
mekuta	palm		transformation
mepepu	fruit		food
metonha	tree		construction/transformation
mikikuré	leaves		food
miko	tree	pau preto	construction/transformation
minana	tuber		food
mitaka	tuber		food
moko	wood		construction/transformation
mokopilo	fruit		food
monko	fruit		food
monkoré	wood		construction/transformation
movala	fruit		food
mpupu	leaves		food
muíla kharamu	wood		construction/transformation
muinti	leaves		food
nakuné	fruit		food
nakuro	leaves		food
Namandjamandja	fruit		food
namara	leaves		food
namarete	leaves		food
nametuko	leaves		food
namitchukuro	leaves		food
nampape	leaves		food
Nanvedjuvedju	fruit		food
napalapala	fruit		food
nassinti	leaves		food
ndjimboe	tuber		food
nekupu	fruit		food
nfuma (muma)	wood		construction/transformation
nhambo	fruit		food
nhapo	fruit		food
nicacarula	fruit		food
nicuto valanka	bark		medicine
nihompe	fruit		food
nihuncua	leaves		food
nkoi	bark (rope)		construction
nkombua	tree		construction/transformation

nkonkoré	leaves		food
nkorokompoé	leaves		food
nkoroma	fruit		food
npukolé	leaves		food
npuma	fruit		food
nrepe	fruit		food
nrikiriki	bark		medicine
nrokopalé	fruit		food
nrou	fruit		food
ntatché	leaves		food
ntchaho	leaves		food
ntete	leaves		food
ntili	tree	pau rosa	construction/transformation
ntintiri	tree		construction/transformation
ntonha	bark (rope)		construction
ntoriro	leaves		food
ntukuti	leaves		medicine
ntumpo	wood		construction/transformation
ntunkuré	leaves		food
nukukuata	fruit		food
pelepetcho	leaves		medicine
pepete	fruit		food
perupé	fruit		food
piri	wood	jambire	construction/transformation
pondo	tuber		food
povó	bark (rope)		construction
pukulo	bean		food
punho	leaves		medicine
rapakalé	fruit		food
rava	fruit		food
salasi	fruit		food
saumpiri	tree		construction/transformation
semuelé	tree		construction/transformation
suampiri	leaves		food
téte	leaves		food
uepa	fruit		food
uiéle	bean		food
ulapa	fruit	*Adansonia digitata*	food
vitoé	fruit		food
ANIMALS			
chérule	bird		food
chicuépe	bird		food
ihopa	freshwatwer fish		food
ihuru	invertebrates		food
ikahka	bird	guineafowl	food

ikarara	invertebrates		food
ikololo	bird		food
ikuali	bird	partridge	food
ikululu	bird		food
inahri	mammal	buffalo	food
inhoto	invertebrates	reptile	food
ipala	mammal	pala-pala	food
ipalali	mammal	antilope	food
ipalavi	mammal		food
ipila	mammal		food
ipuilimiti	invertebrates	ephemera	food
itahta	mammal	antilope	food
iteki	mammal		food
kaúla	bird		food
komopo	bird	green pigeon	food
kutuco	mammal		food
mauinti	invertebrates		food
mituko	invertebrates		food
miunko	invertebrates		food
mkopo	freshwatwer fish		food
nachoro	mammal	duiker	food
nahé	mammal	duiker	food
nanhiata	invertebrates		food
nanrita	invertebrates		food
napéra	invertebrates		food
napiri	bird	partridge	food
nassunuko	mammal	porcupine	food
ndjia	bird	doves	food
nkuerekuere	bird	quail	food
ntuko	invertebrates		food
ukula	mammal	rabbit	food
urango	bird		food
FUNGI			
iulo	fungi	mushroom	food
iuto	fungi	mushroom	food
kapara	fungi	mushroom	food
kokoé	fungi	mushroom	food
kutiki	fungi	mushroom	food
mantetere	fungi	mushroom	food
mapuiaué	fungi	mushroom	food
namarapua	fungi	mushroom	food
namihava	fungi	mushroom	food
nankava	fungi	mushroom	food
ntakuaha	fungi	mushroom	food
ualapa	fungi	mushroom	food

untotolo	fungi	mushroom	food
uoa	fungi	mushroom	food
upuri	fungi	mushroom	food
urenka	fungi	mushroom	food
utacuaha	fungi	mushroom	food
utempo	fungi	mushroom	food
utotoé	fungi	mushroom	food
uvahi	fungi	mushroom	food
uvahilapa	fungi	mushroom	food
FUEL			
makala	plant	charcoal	fuel
ikuni	plant	firewood	fuel
HONEY			
ivalé	honey	honey	food and medicine
pahi	honey	honey	food and medicine
uravo	honey	honey	food and medicine
uta	honey	honey	food and medicine
SOIL			
maué	soil	rock	construction
uloko	soil	clay	transformation
WATER			
maadji	water	water	drink