CLIMATE CHANGE ADAPTATION IN THE QUIRIMBAS NATIONAL PARK, MOZAMBIQUE

CLIMATE CHANGE IMPACT ON MANGROVE ECOSYSTEM AND DEVELOPMENT OF AN ADAPTATION STRATEGY FOR QUIRIMBAS NATIONAL PARK



WWF MCO

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Disclaimers

This technical report is the result of the mangrove assessment and climate change adaptation of QNP. All conclusions and recommendations given are those considered appropriate at the time of the project development. They may be modified in the light of further knowledge at future subsequent stages.

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Acronyms

AFD - French Development Agency

BA - Basal Area

CC – Climate change

CEPAM - Center for Coastal and Marine Environmental Research

CI - Complexity index

D - Stem Density

DBH - Diameter at Breast Height

EBM - Ecosystem-based management

FAO - Food and Agriculture Organization of the United Nations

FFEM - French Fund for the Global Environment

GoM - Government of Mozambique

GPS - Global Positioning System

IPCC - Intergovernmental Panel on Climate Change

IV - Importance Value Index

MRV - Measurement, Reporting, and Verification

NGO – Non-governmental organization

QNP – Quirimbas National Park

RC - Regeneration Classes

REDD+ - Reducing Emissions from Deforestation and Forest Degradation

SLR – Sea level rise

UEM - Universidade de Eduardo Mondlane

UNDP – United Nations Development Programme

UNEP – United Nations Environment Programme

USFS – United States Forest Service

WWF - World Wide Fund for Nature

Executive Summary

Mangrove forests are among the most productive and valuable ecosystems on earth. Worldwide millions of coastal populations benefit from the ecosystem services provided by mangrove forests and to continue to enjoy the enormous benefits provided by mangroves, there is a need to develop climate change-oriented mangrove management programs.

This study was undertaken by WWF under the climate change adaption programme implemented in the Quirimbas National Park (QNP), which preserves one of the largest mangrove areas in the region. This FFEM project is aimed to perform a mangrove ecosystem assessment for Quirimbas National Park (QNP) in order to understand the mangrove forest biophysical and anthropogenic dynamic in the context of climate change and guide the park administration and local communities to the development of an adaptation strategy for climate change for QNP.

This report is a concise assessment of mangrove forest from QNP, written for Park authorities, coastal communities and project managers, who should work in collaboration with decision-makers to put in practice the strategy and recommendations in order to have healthy mangrove forests and efficient plans for the sustainable management of coastal ecosystems.

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1. Background

1.1 Overview of mangroves

Mangrove forests are intertidal communities of trees and shrubs distributed worldwide in tropical and sub-tropical coastline regions (Spalding *et al.,* 1997; Kathiresan and Bingham, 2001; Mitsch and Gosselink, 2007; FAO, 2007; Giri *et al.,* 2011). Mangroves are described as an ecosystem that developed specialized adaptations to live in intertidal environment with variable salinity and tidally-driven inundation, strong winds and anaerobic mineral and organic soils (Tomlinson, 1986; Kathiresan and Bingham, 2001).

This adaptation was achieved by the development of unique structural, morphological, reproductive specializations, including aerial root systems, salt-extracting leaves and viviparous water-dispersed propagules (Tomlinson, 1986; Saenger and Snedaker, 1993; Kathiresan and Bingham, 2001).

Mangrove systems play an integral role at the interface between terrestrial, freshwater and marine systems, by holding an extremely high biodiversity, providing habitat for terrestrial and marine fauna and flora, timber and firewood production, sediment regulation, carbon storage and coastline protection against erosion, sea level rise and extreme events such as storms and tsunamis (Kathiresan and Bingham, 2001; Alongi *et al.,* 2002; FAO, 2007; Komiyama *et al.,* 2008; Cohen *et al.,* 2013). Studies following the 2004 tsunami found that human deaths and loss of property were reduced by the presence of coastal vegetation (including mangroves) shielding coastal villages (Kathiresan and Rajendran, 2005; Walter *et al.,* 2008).

Overall, there are 137.760 Km^2 of mangroves distributed along 118 countries worldwide (Spalding *et al.,* 1997; Giri *et al.,* 2011; Page *et al.,* 2011). Representing alone only 0.7 % of total world forests, they provide numerous economic and environmental services and play an important role in the global carbon (C) cycle and climate change mitigation (Giri *et al.,* 2011).

Despite this importance, mangroves endure enormous pressure from human impacts, with around 35% of the original area degraded or destroyed since 1980 and current global rates of loss running between 1 - 2% per annum (Valiela *et al.,* 2001; FAO, 2007; Donato *et al.,* 2011; Cohen *et al.,* 2013).

While direct exploitation for timber, fuel wood and aquaculture are the main current threats worldwide, raising temperatures, changes in rainfall patterns and the increase of intensity and frequency of storms are likely to become the largest cause of mangrove destruction in the future (Gilman *et al.,* 2008; Paling *et al.,* 2008).

Mangrove forests perform valued regional and site-specific functions (Walters *et al.,* 2008). Reduced mangrove area and health will reduce the accessibility to the ecosystem services and will increase the threat to human safety and shoreline development from coastal hazards such erosion, flooding, storm waves and surges (Kathiresan and Rajendran, 2005; Dahdouh-Guebas *et al.,* 2005; Williams *et al.,* 2007).

Adaptations and resilience enhancement, strengthening the protected areas strategies, extensive mangrove rehabilitation programs, regional monitoring network establishment and start-up of environmental education programs are the main objectives, among others, to support a long term adaptation mangrove program of resistance and resilience to climate change (Gilman *et al.,* 2008).

1.2 Climate Change

Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere in land use (IPCC, 2007).

Concepts such as vulnerability, adaptation and increased resilience to climate change emerged as mechanisms to reduce the impacts of stressors (Lovelock and Ellison, 2007; Ellison, 2010; Murdiyarso *et al.,* 2012). Vulnerability is the susceptibility of exposure to harmful stresses and ability to respond to those stresses (Adger *et al.,* 2007). Adaptation is a response to current and expected impacts on natural ecosystem and humans, which can exploit benefits (Houghton *et al.,* 2001; Ellison, 2010), while resilience is the ability to continue to function in the face of change (Houghton *et al.,* 2001; Ellison, 2010).

Reducing the vulnerability or increasing the resilience of wetland ecosystems to climate change is critical because catastrophic impacts are predicted specially for developing countries where economies and livelihoods depend largely on the capacity of these ecosystems to provide services to sectors and society, especially fishery productivity (Vignola *et al*., 2009).

Current knowledge indicates that climate change effects on mangroves are significant, may already be occurring, and will continue to occur (Gilman *et al.*, 2008; Ellison, 2010). Climate change components that affect mangroves include changes in sea-level, high water events, storminess, precipitation, temperature, atmospheric CO_2 concentration, ocean circulation patterns, health of ecosystem linkages with neighbouring ecosystems, as well as human responses to climate change (Lovelock and Ellison, 2007; Ellison, 2010).

Other forces such as territorial planning, population growth, coastal development, lack of governance, over-exploitation of natural resources and other human forms of degradation and the current "climate stressors" will increase the vulnerability to climate change (Gilman *et al.,* 2008; Ellison, 2010; Tobey *et al.,* 2010; Murdiyarso *et al.,* 2012).

The evidences related to mangroves vulnerability and the capacity to reduce the impact of climate changes effects is widely reported (Ellison, 1993; Kathiresan and Bingham, 2001; Kathiresan and Rajendran, 2005; Gilman *et al.,* 2008; Magris and Barreto, 2010; Ellison, 2010; UNEP, 2014). Thus, mangroves could be key ecosystems in strategies addressing the mitigation of climate change and adaptation mechanisms are needed to respond to mitigation Kauffman *et al.,* 2011). Successful adaptation involves the reducing current threats (deforestation and degradation) along with the mitigation of climate change impacts.

Governmental authorities are encouraged to assess coastal ecosystems vulnerability to climate change and institute appropriate adaptation measures to provide adequate lead time to avoid and minimize social disruption and cost, minimize losses of coastal ecosystem services and maximize available options (Gilman *et al.*, 2008; Sierra-Correa and Kintz, 2015).

Regarding to management of mangrove forests, it requires the development of an adaptive resource management strategy according to the vulnerability and resilience to climate change (Gilman *et al.,* 2008; Ellison, 2010; Murdiyarso *et al.,* 2012).

1.3 Mangroves and Climate Change in Mozambique

About 20% of the world´s mangroves are in Africa (Giri *et al.*, 2011). Globally, Mozambique rank 13th in mangrove coverage and within Africa has the third largest mangrove cover with 300.000 Km^2 (Giri *et al.,* 2011). These figures are equivalent to approximately 2.3% of the global mangrove forest area (Giri *et al.*, 2011).

In Mozambique mangroves occur in protected shoreline, deltas and estuaries that are distributed all along the coastline (Figure 1) (Barbosa *et al.*, 2001).

There are nine mangrove species in Mozambique (Barbosa *et al.*, 2001). The dominant species are *Avicennia marina* (Forssk.) Vierh., *Bruguiera gymnorrhiza* (L.) Lam., *Ceriops tagal* (Per.) C.B.Robinson, *Rhizophora mucronata* Lam. and *Sonneratia alba* Smith. Others are *Heritiera littoralis* Aiton, *Lumnitzera racemosa* Willd., *Xylocarpus granatum* Koenig and the fern mangrove, *Acrostichum aureum* L. (Barbosa *et al.*, 2001).

In Mozambique mangroves are used for building, firewood, fencing, fish trapping and medicine (Barbosa *et al.*, 2001). The main issue concerning mangrove conservation in Mozambique is deforestation (Taylor *et al.*, 2003). Other destructive forms of mangrove use are conversion for salt production and aquaculture as an emerging industry in Mozambique, which was responsible for the clearance of relatively small areas in Maputo Bay, Sofala, Quelimane and Pemba (Barbosa *et al.*, 2001).

Regionally, Mozambique is recognized as one of the countries in Africa more vulnerable to climate change impacts due its geographic location (INGC, 2009ab). Therefore, the impacts of climate change such as droughts, floods, variable and heavy rains, sea-level rise, strong winds and tropical cyclones are already significantly affecting the country (INGC, 2009a).

Climate change (CC) poses a serious challenge to social and economic development. In Mozambican coastal areas, approximately 20% of the population´s economy depends on climate-sensitive natural resources that are under severe risk (MICOA, 2013).

According to recent studies, a substantial loss of mangrove forests and tidal wetlands along highly dynamic and exposed coastlines in some parts of the country are caused by natural impacts (including climate change impacts) such as sea level rise, high erosion energy of tidal waves, increase of storm surges and significant sedimentation under mangroves (Hoguane, 2007; INGC, 2009ab; INGC, 2012).

In Mozambique, mangroves are protected by the National Conservation Law (No 16/2014) and may only be harvested for local subsistence and research purposes. They are also protected under the Forestry and Wildlife Act (No 10/1999), which includes forests and wildlife in protected areas. Despite the existence of laws all mangroves out of the protected areas are not effectively protected and are therefore more exposed to threats of deforestation and degradation.

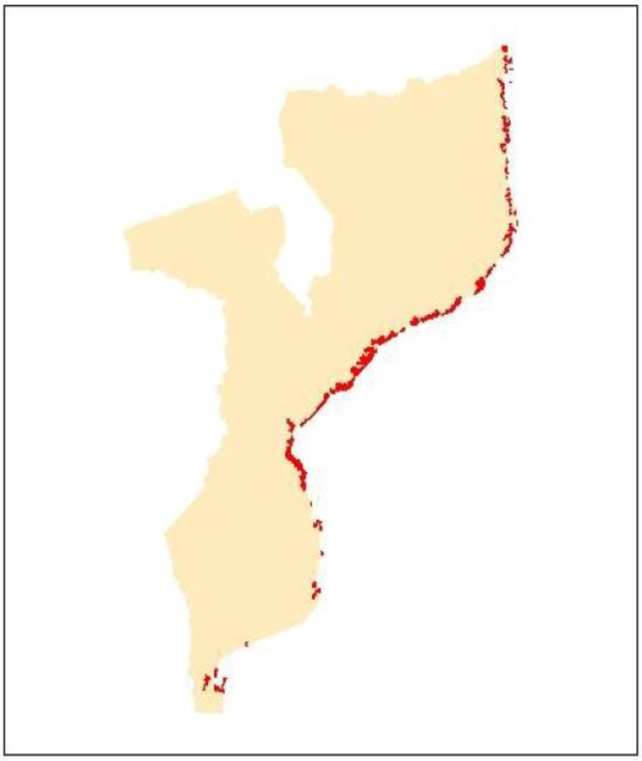

Figure 1 – Mangrove distribution in Mozambique (Source: USFS report, 2014 from Giri *et al.*, 2011).

1.4 Climate change: history and predictions

1.4.1 Mozambique Climate

Mozambique is located on the eastern coast of southern Africa between 10°S and 26°S, 30°E and 40°E (INGC, 2009b). The climate is tropical, characterized by two seasons: a cool dry season from May to September and a warmer wet season from October to April. Average temperatures in the country are around 25-27°C in the wet season and 20-25°C in dry season (INGC, 2009a). The rainfall distribution in the country follows an east-west gradient, with more abundant rainfall along the coast. An annual rainfall average varies between 800 and 1200 mm within each annual cycle with 60-80% of the annual precipitation occurring in the warm season (INGC, 2009ab). The inland and higher altitude areas in the northern regions of Mozambique experience cooler average temperatures of 20-25°C in the warm season and 15-20°C in dry season (McSweeney *et al.*, 2008).

Mozambique's coastal location means that it lies in the path of highly destructive hurricanes and cyclones that occur during the wet season associated with heavy rainfall. Between 1980 – 2007, 15 cyclones made landfall on the Mozambican coast, 8 of which in the central districts of the country, and 3 and 4 respectively in the northern and southern regions (Mavume, 2008).

In this context, the Government of Mozambique (GoM) developed the National Strategy for Climate Change (2012) in order to reduce the climate change vulnerability and to improve the livelihood through the implementation of adaptation measurements promoting sustainable development.

1.4.2 Mozambican Historical Climate Data

Mozambique is recognized as one of the countries in Africa with high vulnerability to climate change impacts due its geographic location (INGC, 2009ab). There is little information about climate historical trends in Mozambique (INGC, 2009b). In the last decades the Government of Mozambique has been committed to address the climate change mitigation and the National Institute for Disaster Management (INGC) is leading major activities and researches related to climate change in the country.

The major available climate change data of Mozambique is compiled in the INGC (2009ab) reports and according to that reports, Quirimbas National Park (QNP) is located in a moderate/low vulnerable coastal area for hazards in Mozambique (Figure 2). Some specific areas will be impacted by climate change and a new goal was defined in the last QNP Management Plan (MITUR, 2014) taking in account the vulnerability of mangrove ecosystems. According to this information, adaptation measures should be applied to prepare the QNP and communities to the expected climate change impacts. Related to mangroves, some climate change adaptation and monitoring activities including, analysis of vulnerability, biodiversity, recent spatial changes of mangroves, ground elevations in and behind mangroves, relative sea level trends, sedimentation rates under mangroves, adjacent ecosystem resilience, climate (rainfall) modeling and compilation of local community knowledge should be assessed.

This climate chapter is based on the climate data provided in the INGC (2009ab), INGC (20120) reports and Mavume (2008).

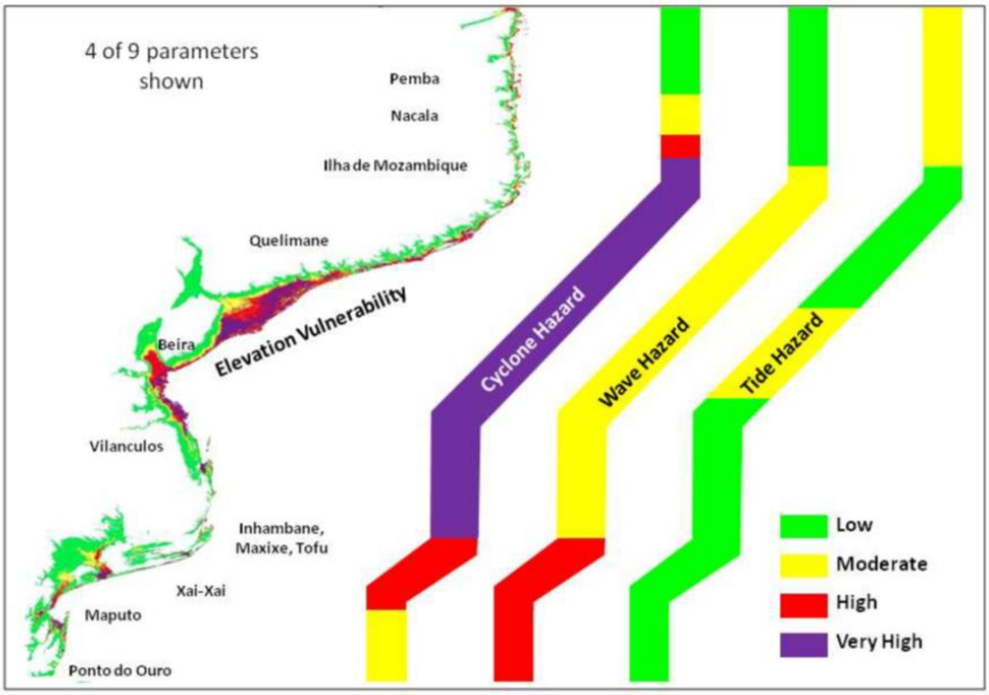

Figure 2– Hazards and vulnerability of Mozambican coast (Source: INGC, 2012).

Temperature

During the period of 1960 – 2005 positive temperature trends in Mozambique were verified, temperature increasing by (0.6°C – form 1960; averaging 0.13°C/ per decade) (Table 1), particularly during the rainy season (INGC, 2009b). However, the warming tendency has not been uniform across the country: in the north maximum temperatures during the dry and wet season have increased by approximately 1.1°C (INGC, 2009b).

Precipitation

Annual rainfall between 1960 and 2005 has decreased by 2.5 mm per month (3.1%/per decade) (Table 1). In Mozambique this decrease in rainfall is observed mainly during the rainy season leading to long dry seasons (McSweeney *et al.*, 2008).

Tropical Cyclones

Mozambique is ranked the third African country most affected by extreme weather events (INGC, 2009a). Mozambique's coastal regions are in the path of highly destructive tropical cyclones that occur during the wet season, and which are often associated with heavy rainfall events that may contribute a significant proportion of annual rainfall in a very short period (INGC, 2009b). Overall, frequent extreme weather events have resulted in approximately 35% of the total Mozambican population being considered chronically food-insecure. Between 1980 and 2003, the economic losses attributable to extreme weather events in Mozambique totalled US$ 1.74 billion (INGC, 2009a).

In the period, 1980-2007, 56 cyclones were tracked by satellite to have entered the Mozambique Channel. This is an average of two cyclones per year for this period, (Mavume, 2008). The more intense cyclones were accompanied by extreme weather with intensive rain, resulting in major flooding and damage to infrastructure along the rivers and the coast (Mavume, 2008).

About 4 of the cyclones occurred in the period from 1980-1993, the other eleven (11) cyclones hit the coast in the later period of 1994-2007 (INGC, 2009a).These observations indicate an increase in frequency and intensity of tropical cyclones, however, the INGC report (2009b) highlights that the record and number of events is too limited to confirm statistically significant trends.

Examples of high category cyclones that made landfall during this period are the intense tropical cyclone Jokwe moved over northern Mozambique and caused rainfall in excess of 200 mm in Nampula (some 150 Km inland). Other examples of wettest cyclones are TC Eline in 2000 (~500 mm), TC Delfina in 2003 (~281 mm) and TC Japhet in 2003 (~190 mm) (Mavume *et al.*, 2008). In late March 2014 cyclone Hellen's associated rainfall and strong winds affected the QNP area and its islands.

Sea level Rise (SLR)

Church *et al.* (2004) identified regional patterns of sea level rise from tide gauge records in the region between 1950 and 2000. For the southern part of Africa a sea level rise of about 1.0 – 2.5 mm/ year is estimated.

The results demonstrate a clear regional pattern, features of which are consistent with other known changes in the climate system. Accordingly, much of the coast of Mozambique is vulnerable to sea level rise and the trends show an increase of 30 cm by 2010 (Table 1). The potential damage will increase vulnerability of coastal populations and ecosystems (INGC, 2009b).

Flooding

More than a hundred hydrographic basins have been identified across Mozambique according to INGC (2009a). However, more than 50% of Mozambique's surface runoff is generated in neighbouring countries, which makes Mozambique vulnerable to changes in the water dynamics of neighbouring countries (INGC, 2009a).

The period of 1960 to mid-1980 was characterized by minimal flood activity; major floods return again at the beginning of the year 2000 resulting in negative impacts to the local communities and leading to accretion of sediments to the estuarine areas (INGC, 2009a).

The results indicate that while the climate models have some difficulty figuring out exactly where rainfall events will occur, there is a general expectation of increased flood peaks in small watersheds wherever storms make landfall.

Table 1 – Historical and future climate trends for Mozambique (INGC, 2009a; 2009b).

		Projected Changes	
Climate Variables	**Change 1960 - 2005**	**2060**	**2090 /2100**
Temperature increase	+0.6	+1.0 to 2.8	+1.4 to 4.6
Mean annual temperature (ºC)	+1.1	+2.5 to 3.0	+5.0 to 6.0
Maximum temperatures (ºC)	+25; +11	+ 25 - 35	+ 26.0 – 76.0
Total precipitation	-3.1%/decade	Large variation in models	-15% to +34%
Proportion of precipitation falling in heavy rainfalls	+2.6%/decade	+15%	-
Low sea level rise scenario	-	20 cm	30 cm
High sea level rise scenario	1.3 to 2.3mm/ year	100 cm	500 cm

1.4.3 Future Changes in Climate for Mozambique

There are several worldwide models for climate change scenarios however in this section we will review climate scenarios as illustrated by McSweeney *et al.* (2008) and INGC (2009ab).

Temperature

The mean annual temperature is projected to increase by 1.0 to 2.8°C by 2060, and 1.4 to 4.6°C by 2090 (McSweeney *et al.,* 2008) (Table 1). All different General Circulation Models (GCMs) used by INGC (2009b) presented project maximum temperatures increasing between 2.5°C and 3°C (median estimate of all GCMs). By 2081-2100 increases in temperature are projected to as much as +5 - 6°C over the country in the dry season (INGC, 2009b).

Precipitation

Projected trends of precipitation will increase at least 15% in the north part of the country (INGC, 2009b). Seasonally, rainfall is likely to decrease during dry season but increasing during the wet season (INGC, 2009a). It is however important to point out, that rainfall increases are less than increases in evapotranspiration during the dry season (INGC, 2009a). This indicates that the dry season will become drier everywhere in the future. A significant decrease in soil moisture before the main cropping season starts could result (INGC, 2009a).

Cyclones and sea level rise scenarios (2030–2100)

Northern of Mozambique is characterized by a relatively narrow coastal plain with few large rivers, a coastline of sandy beaches, sea grass meadows and fringing coral reefs, and a narrow continental shelf (Hoguane, 2007). The tides are moderate (2m in range), and the coast is subject to occasional tropical cyclones (4 of 11 in the past 16 years).

Models suggest that for the Indian Ocean there is an overall tendency toward decreasing frequency of tropical cyclones but increasing cyclone intensity (INGC, 2009a). With the respect to sea level rise, there appear to be two groups of sea level rise scenarios:

1. The Low Sea Level Rise (Low SLR) scenario is based largely on thermal expansion of sea water, only; 2. The High Sea Level Rise (High SLR) scenario, which represents the worst

case scenario, is the rapid dynamical changes in ice flow due to continental ice melting in the Polar Region.

In the Low SLR scenario, tropical cyclones will remain the main threat to the coast of Mozambique; coastal erosion is likely to be episodic and associated with extreme storm events (INGC, 2009a). With the low SLR of 30 cm by 2090 coastal set-back will reach approximately 30 m (INGC, 2009a). The INGC study (2009b) reveals, that only very few areas along the coast are at risk, specifically the low-lying offshore islands of Quirimbas Archipelago.

Flooding

The hydrological analysis of INGC (2009a) looks at future river flow behaviour, saline intrusion and river water demand versus supply, incorporating future rainfall projections, population growth, topography, soils and land cover parameters. Ocean tides are the largest natural force affecting sea water intrusion into river systems. Influences of sea level rise and storm surge appear to be of much smaller magnitude, certainly until 2030 (INGC, 2009a). At current per capita usage rates, all river reaches have adequate water to meet demands, but with projected population growth, about 60% of river reaches will become water scarce by mid-century (INGC, 2009a).

Salt water intrusion does not pose a major problem for the river systems in the north, as the landscape is generally more rugged with steeper slopes along the river channels (INGC, 2009a).

2. Project Context

The current FFEM project is entitled “Climate change adaptation in the Quirimbas National Park, Mozambique”. This is a 5 year project funded by the French Fund for the Global Environment (FFEM), French Development Agency (AFD), the Government of Mozambique and the World Wide Fund for Nature (WWF).

The general objective of this FFEM project is to “Improve the resistance and resilience of the ecosystems of Quirimbas National Park to Climate Change”. The overall outputs of the project includes: set up the administrative structures of the park; involvement of local communities in park management; reduction of pressure on natural resources; better management of marine resources and prepare the park ecosystems to the climate change.

2.1 Project Activities Components

This FFEM project is divided in 4 specific components:

- Component 1: Studies on climate change impact on critical ecosystems and development of adaptation strategy;
- Component 2: Increasing marine ecosystems resilience to CC through better management;
- Component 3: Increasing terrestrial ecosystems resilience to climate change through connectivity;
- Component 4: Revenues from conservation: payments for ecosystem service.

2.2 Research Objectives

2.2.1 General Objective

Within the component 1 of the project, the main objective of this research is to: "Perform a mangrove ecosystem assessment of Quirimbas National Park (QNP) in order to understand the mangrove forest biophysical and anthropogenic dynamic in the context of climate change that can guide the park administration and local communities in the development of an adaptation strategy for the QNP and buffer zones."

2.2.2 Specific Objectives

The specific objectives of this study are:

a. Conduct a mangrove change-detection analysis of relevant satellite imagery to assess changes on mangrove cover within QNP and its buffer zone over a 20 year timeframe up to the present.

b. Describe the mangrove forest structure status and assess to the current level of cutting and regeneration status of mangrove forests on QNP.

c. Develop climate change scenarios for biophysical impact assessment of climate change on mangrove ecosystem.

d. Identify the main gaps in the present state of climate change knowledge in relation to the current and possibly future management objectives of the QNP.

e. Develop an adaptive resource management strategy that involves local community to improve the resistance and resilience of the mangrove ecosystem of Quirimbas National Park to climate change.

2.3 Research Questions

The following questions are formulated in this research:

- What is the current mangrove extent at QNP?
- What is the mangrove forest cover and what are the structural attributes affected by human-induced and climate-change factors?
- Do mangrove forests in the QNP have potential to regenerate by themselves in order to compensate the change in composition following the mangrove degradation or any CC impacts?
- Does the QNP have an equitable relationship between the ecosystem services provided by mangrove forest and the current degradation?

2.4 Significance of this research for the project

The current research generates maps of mangrove cover change, an ecological report of mangrove structure, species diversity, anthropogenic pressure status, regeneration status and analysis of the climate trends and design of mangroves adaptations for climate change impacts in the QNP. Therefore, this research develops the baseline information for mangroves and creates a conceptual model to support the project goal of "*Maintenance of the integrity of the natural resources of the Quirimbas National Park for the benefit of local people in the context of climate change".*

3. Methodology

3.1 Geographical and Socioecological Context the Quirimbas National Park

Cabo Delgado Province is the northernmost province of Mozambique characterised by a pronounced dry season (April to October). The average annual rainfall ranges from 800 mm to 1.400 mm. The province has 17 districts, with a human population estimated at 1.797,335. Agriculture and fishery are the main subsistence sources for local communities (INE, 2013; MITUR, 2014).

The rapid increase of coastal populations, tourism and the recent growth of the extractive sector in the Province (oil and gas) put considerable pressure on natural resources particularly on marine ecosystems including mangrove forests.

The Quirimbas National Park was created on 6th June 2002 from Council of Minister Decree N°14/2002. The park partially covers 4 districts (Meluco, Pemba-Metuge, Ancuabe e Macomia) and totally the districts of Ibo and Quissanga. The PNQ has a total area of 9.130 Km^2, of which 1185 Km^2 are marine and 7,945 Km^2 of the land part. The park has a buffer area defined of 10 Km along the park boundaries covering an area of 5.704 Km^2.

The marine part of the Park contains the 11 most southern islands of the Quirimbas Archipelago the most important are Ibo, Matemo, Quisiwe, and Quirimba. The islands have a long history of permanent human occupation. The remaining park islands are Quipaco, Mefundvo, Quilalea, Sencar, Quirambo, Fion and Ilha das Rolas. The Park extends for about 100 Km from the mouth of the Rio Tari in the south, through the Ponta do Diabo to Mucojo village in north in the district of Macomia (Figure 3) (MITUR, 2014).

The QNP is considered a regional and global priority area for biodiversity conservation due to its miombo and coastal woodlands, spectacular granite outcroppings holding many endemic succulent plants, marine turtles, species-rich coral reefs, seagrasses and mangrove ecosystems (MITUR 2009; MITUR, 2014).

The human factor within the QNP is quite complex, more than 150.000 people live in 91 villages inhabit permanently the park and there are an additional 30.000 people living in the buffer zone (Table 2) (INE, 2013; MITUR, 2014). The population is concentrated mainly along the coast (20% of the QNP population) and along the main roads that cross the park. As elsewhere in the province, the education level is low (illiteracy rates average 83%) and 95% of the economically-active population works in small-holder agriculture, on family-run farms and small-scale fishery.

Table 2 – Population distribution in the 3 coastal districts of the QNP (Source: INE, 2013).

District	Area (Km^2)	Total Population	Population Density
Macomia	4.252	87.283	20.5
Quissanga	2.150	39.928	18.6
Ibo	75.0	10.828	1.44.3
Total Province	78.778	1.797,335	90.0

Mangrove forests in the QNP are important for local communities in providing timber, firewood, medicine and the economic potential for recreation and tourism development (MITUR, 2009). They play an important role as a protective barrier against erosion, sea level rise (SLR), tropical cyclones and storms and floods. Mangroves also provide nursery grounds for fisheries (thus sustaining livelihoods of local communities) (Barbosa *et al.*, 2001).

Despite the recognised importance, the mangrove forests of the QNP are threatened by land use activities and change, intensive harvesting and urbanization. Anthropogenic pressure is high because of timber exploitation for boats and house construction and firewood to support the lime Industry (FFEM, 2011). The lime is sought for construction in coastal areas of QNP and is produced in lime kilns fueled with both limestone and coral with rock. These furnaces usually operate with large amounts of mangrove wood (FFEM, 2011).

Mechanisms to improve the resilience of mangroves in QNP are required and include: i) management of anthropogenic stresses including human access, dredging, sedimentation, and nutrient enrichment; ii) zoning and board walk usage; iii) rehabilitation of degraded areas; iv) representative PA networks and sustainable harvesting (MITUR, 2003).

3.2 Study Area

The present research was conducted in the mangrove area of QNP located between the districts of Macomia and Metuge (Figure 3). The Park is located between the Latitudes 12 ° 00 '00 "and 12 ° 55' 04" South, and Longitude: 39 ° 10 '00 "and 40 ° 39' 44" East (MITUR, 2003).

The QNP extension is approximately 100 Km starting from the mouth of Tari River, up to Mucojo village in Macomia District, including the undersea of the Banco de S. Lázaro, which is located 42 nautical miles east of Ibo Island (MITUR, 2003).

The climate of the region is tropical with two seasons occurring each year, wet and dry seasons, where average temperatures vary between 25°C and 27°C. Rainfall is restricted to the warm season from November to April.

There are six mangrove species in the Quirimbas Archipelago coast: *Avicennia marina*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Rhizophora mucronata*, *Sonneratia alba* and *Xylocarpus granatum* (Barbosa *et al.*, 2001; Hoguane, 2007; Bandeira *et al.*, 2009).

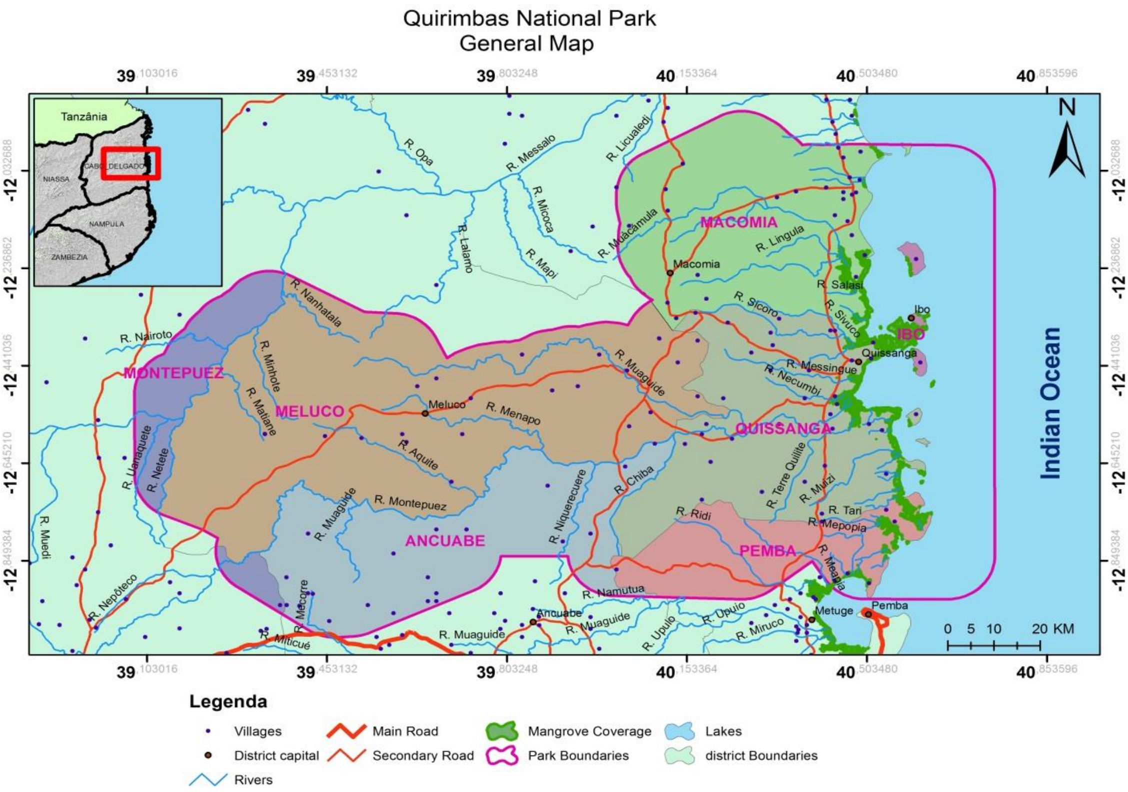

Figure 3 - Geographic Location of Quirimbas National Park.

3.3 Mangrove Cover Change Detection

The mangrove change-detection was based on analysis of relevant acquired satellite imageries supported by groundtruthing, to assess the land cover change in mangrove forests within the QNP over a 20 year timeframe up to the present (Figure 4). It includes:

3.3.1 Image acquisition and processing

To estimate the extent of mangroves on Quirimbas National Park, Landsat images were used. Landsat Imagery is freely available for download on the USGS (United States Geological Survey) online satellite imagery repository: GloVis platform (USGS Global Visualization Viewer). The platform contains much of global satellite images generated by Landsat series sensors: OLI 8 (Orbital land Imager 8 or Landsat 8), ETM 7+ (Enhanced Thematic Mapper Plus or Landsat 7), and TM5 (Thematic Mapper 5 or Landsat 5).

Quirimbas National Park (QNP) involves two Landsat images: path /row 164/068 and 164/069. Images from 1991, 2002 and 2013 in the respective path/rows were acquired for the study (Table 3). Each pair of images is representative to the decade they belong. All the images have minimal cloud cover.

Table 3 – QNP Landsat images and respective paths/rows.

Sensor	Path/Row	ID	Acquisition Date	Spectral Bands
TM 5	164/068	LT51640681991231JSA00	19-08-1991	1-5, 7
TM5	164/069	LT51640691991231JSA00	19-08-1991	1-5, 7
ETM+ 7	164/068	LE71640682002125JSA00	04-05-2002	1-5, 7
ETM+ 7	164/069	LE71640692002125JSA00	04-05-2002	1-5, 7
OLI 8	164/068	LC81640682013147LGN00	26-05-2013	1-7, 9
OLI 8	164/069	LC81640692013147LGN00	26-05-2013	1-7, 9

All Landsat imageries acquired in the USGS repository are geometrically corrected. Spectral bands were stacked in one file per images in order to make colour composition assist visual interpretation a post-classification process. For Landsat 5 and 7, composition 543 was used and for Landsat 8 were 654.

3.3.2 Mangrove mapping and land change analysis

The classification process consisted of a hybrid process, which included an unsupervised algorithm followed by a supervised. The unsupervised process includes the use of k means algoritm in order to get the statistical distribution of spectral classes along the image. Land use classes are assigned to the spectral classes identified and samples were collected to train and validate the supervised algorithm. Maximum likelihood supervised algorithm was used to the second stage classification process resulting in a land use classification for each image. The main land use classes identified were: mangrove, mud, sand, water and terrestrial areas.

Validation was done using an independent dataset of mangrove plots and samples of other classes acquired through Google-earth high resolution imagery. Confusion Matrices and classes accuracy were estimated for each image classification. The confusion matrix allows the visualisation of the supervised classification performance based on the sample provided. The diagonal line represents the number well classified pixels by the supervised classification algorithm. Tables with class accuracy and the images overall accuracy was also be provided in order to evaluate the algorithm performance to identify each class, particularly for mangrove class. The mapping resulted in:

- Analyze mangrove vegetation cover change between 1991 and 2013;
- Identification of 3 main community status according to composition and land use: areas of mangrove loss, new colonization and natural forest regeneration.

3.3.3 Assessment of mangrove deforestation status and future modeling

Method of use polygons was done on the three images confusion matrices calculated to obtain producer’s and user’s accuracy and the subsequent overall classification accuracy.

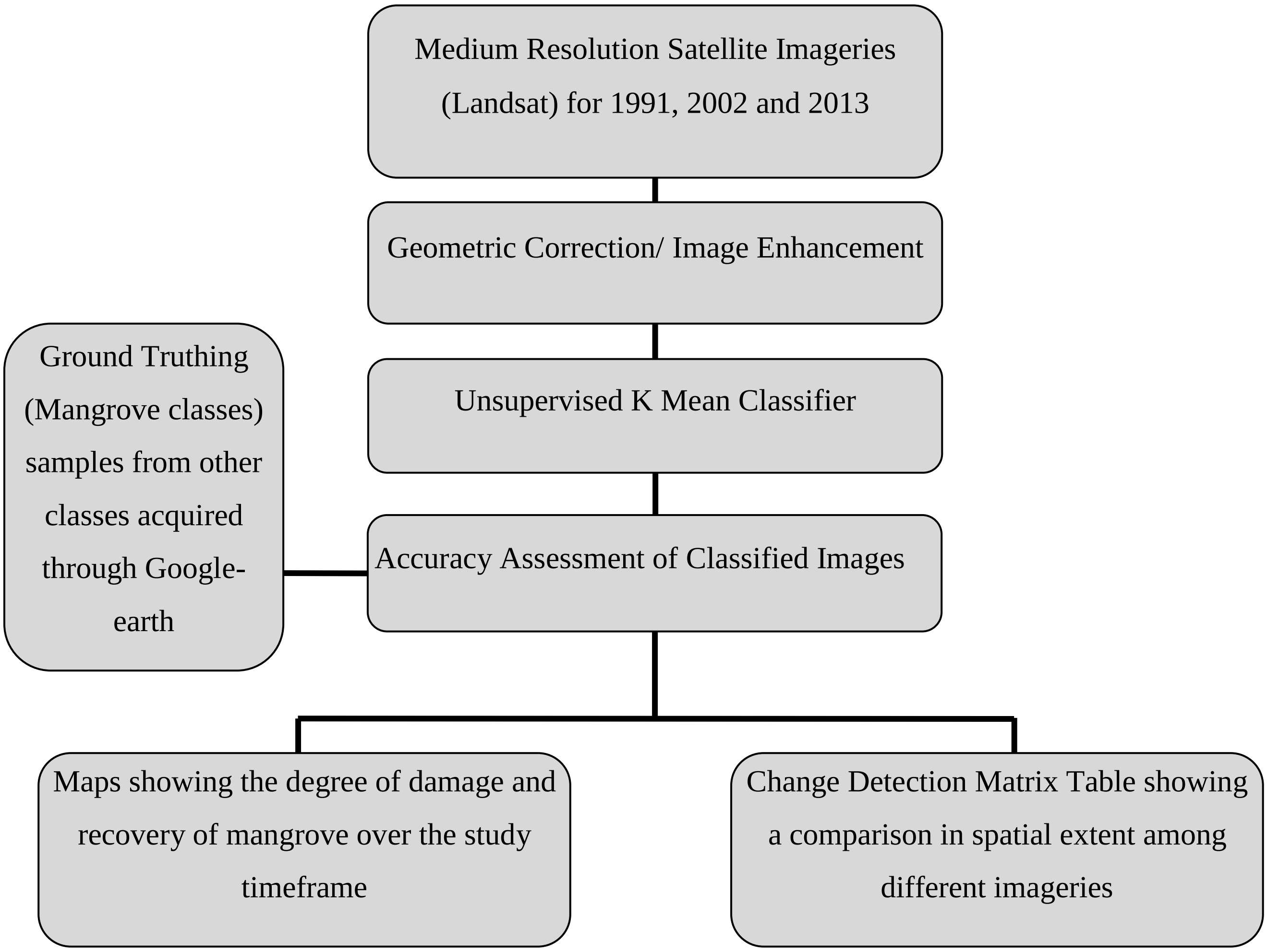

Figure 4 – Change detection analysis procedures for mangrove in the QNP.

3.4 Mangrove Structure and Regeneration Status

3.4.1 Structural Parameters

The sampling design used to assess the mangrove structure of QNP was based on a combination of the protocol developed by Kauffman and Donato (2012) and the applied methodology to assess mangroves forest structure (Kairo *et al.*, 2002; Bandeira *et al.*, 2009).

From the classification and mangrove change detection maps, the research area was systematically classified in 3 regions (subsampling areas) on the ground: north, center and south.

A number of 31 plots were randomly set within the QNP (Appendix 2) based on the assumption that they represent all pre-identified mangrove species and ecotypes (juveniles, intact forest and degraded forests) and the gradients of heavily impacted to fairly undisturbed (less impacted) areas, and with consideration for accessibility to woodcutters and distance to land. By walking 50 m towards north and south and then 50 to east and west, 4 sub-sampling points (sub-plots) were marked, where 10x10m quadrates were set (Figure 5).

The purpose of this method arrangement is to increase the likelihood of capturing the true variation within and across strata (Howard *et al.*, 2014).

Subplot characteristics were collected such as: geographic coordinates, % of canopy cover, inundation class, ecological condition and land use (intact, degraded or deforested); topography (flat, depression, levee or hummock, etc); geomorphologic setting (river estuary, coastal fringe, interior or basin, etc); soil description (organic or mineral soil – sand, clay and silt); disturbance evidence/climate change induced natural threat: sedimentation/erosion ; timber harvest evidence, diseases or other disturbance(not evident, light, moderate or severe).

All trees within quadrates with Diameter at Breast Height (DBH) ≥ 2.5cm were identified and counted, and their diameter at 130 cm (D_{130}) and height (m) were recorded. For stilt rooted species (e.g. Rhizophora sp.), stem diameter was measured above the highest stilt root (Kairo *et al.*, 2002; Komiyama *et al.*, 2005; Bandeira *et al.*, 2009; Kauffman and Donato, 2012).

From the data collected we derived the information on the composition, diversity, structural parameters and community indices (Basal Area, Stem Density, Complexity index, Importance Value Index) together with diameter size class distribution and height profile, to describe the structure and composition of the forest (Dahdouh-Guebas and Koedam, 2006b).

The complexity index CI (I_c) of the forest was obtained as the product of number of species *(s)*, basal area (m^2/ha) *(BA)*, maximum tree height (in meters) *(h)* and number of stems ha-1 *(d)* x 10-5 (Holdridge *et al.*, 1971). Importance value index (IV_i), describing the structural role of individual tree species in the habitat was calculated following (Dahdouh-Guebas and Koedam, 2006b).

$$IV_i = \text{Relative Density} + \text{Relative Dominance} + \text{Relative Frequency}$$

Relative Density = (d_i/D) x100

Relative Dominance = (d_i/D) x100

Relative Frequency = (x_i/X) x100

Where:

d_i = number of individuals of the i_{th} species present in sample population (density), D= total number of individual in sample population $(D= \Sigma\ d_i)$; and xi = sum of basal area for i^{th} species (dominance), X = total of basal area across all species $(X= \Sigma\ x_i)$; and n_i = number of sampling units where ith species is present (occurrence), N = total number of sampling units.

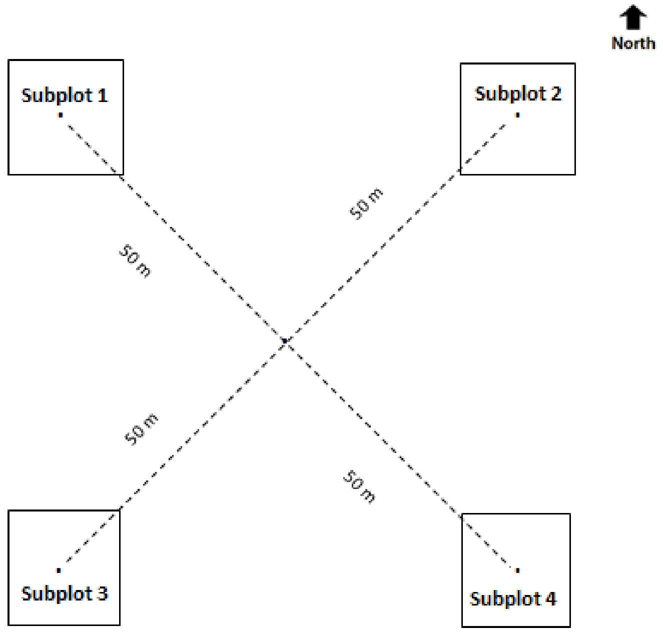

Figure 5 - Rectangular plot layout with four subplots adapted from Kauffman and Donato (2012).

3.5 Conservation Status

The conservation status was assessed by the level of cut according to the methodology described by Cintron and Schaeffer-Novelli (1984), FAO (1994); Kairo *et al.* (2002) and Kauffman and Donato (2012).

To assess mangrove conservation adult individuals in the quadrate were counted and grouped into four degradation categories. These were: *Intact*, for trees with no sign of cut; *Partially cut*, for those with one or more branches which had been cut, but the main trunk is intact; *Severely cut*, with most branches cut; and *Stump*, for those whose main trunk had been cut and *Die back* for the ones dead for natural causes (Kairo *et al.,* 2001; Bandeira *et al.,* 2009). Diameter of stumps was measured to estimate preferred sizes for cutting. The measurements of dead standing trees are the same as for live trees.

The morphology of the sampled trees reflected the usage quality of available poles and was assessed based on the form of the lead stem, which was categorized either as Form 1, 2 or 3. *Form 1* stems denote those whose lead stem is straight and therefore excellent for construction but *Form 2* stems need slight modification to be used for construction. Poles which are unsuitable for construction were assigned *Form 3* (Kairo *et al.,* 2001; Kairo *et al.,* 2008).

3.6 Regeneration Classes

Within the sample sub-plots 5 x 5 meters subplots (quadrat) were set and all trees with a diameter at breast height (DBH) ≤ 2.5 cm were identified and counted. The frequency of each species was recorded and juveniles were grouped in three classes based on height, (RC) I, II or III. Seedlings less than 40 cm in height were classified as regeneration Class I (RCI); saplings between 40 and 150 cm height were classified as RCII, while RCIII was for all small trees with heights greater than 1.5 m but less than 3.0 m as described by Kairo *et al.* (2002); Kairo *et al.* (2008) and Bandeira *et al.* (2009).

4. Statistical Analysis

All data analysis and graphical presentation were obtained with the STATISTICA 12.0 program. The relative density, dominance and frequency were estimated and the importance values established according to Kairo *et al.* (2001) and Dahdouh-Guebas and Koedam (2006). One-way ANOVA at 0.05 probability tests was performed on stocking densities of different size classes, stem densities, DBH and height (m) between sites and species to describe the structure and composition of the forest.

5. Climate Change Scenarios

Mangrove forests are likely to be affected by climate elements associated with climate change, such as changes in rainfall, temperature, atmospheric CO_2 concentrations, sea level, high water events, cyclones and storms, and ocean circulation patterns (Gilman *et al.*, 2008).

There are available multiple global circulation models that represent historical and future trends for the main climate elements (rainfall, temperature and sea level rise). This study used NASA GISS-E2-R model (E2 version of the Goddard Institute for Space Studies) and four greenhouse gas concentration (not emissions) trajectories (Table 4) adopted by the IPCC for the fifth Assessment Report (AR5) (IPCC, 2013).

NASA GISS-E2-R model (E2 version of the Goddard Institute for Space Studies) data from future trends was used to project the climatic changes for 2050 and 2070 using climatic elements such as temperature (maximum and minimum) and precipitation generated by interpolation of world meteorological stations ground data (Hijmans *et al.*, 2005).

Pathways (RCP´s) are used for climate modelling and research. These four greenhouse gases scenarios were used to project the possible climate futures, depending the greenhouse gases emitted in the next years in mid-and late 21st century (2050 and 2070 averages, respectively). Global warming (T^{a}) and global mean sea level rise from the IPCC (2013) are tabulated below (Table 4).

Based on the data of the NASA´S model for this study was assessed the expected changes on the climate elements of different scenarios (RCP´s) specifically for Quirimbas National Park (QNP).

Recent available climate data developed by INGC was assessed for climate analysis using historical data from 1960 to 2005 periods and up to present and downscale future scenarios for mid-century (2046-2065) and late-century (2080-2100) periods in Mozambique.

Table 4 - Projected change in global mean surface air temperature and global mean sea level rise for the mid- and late 21st century (IPCC, 2013).

		2050		2070	
	Scenario	**Mean**	**Likely range**	**Mean**	**Likely range**
Global Mean Surface Temperature Change (^{0}C)	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	0.4 to 2.6	3.7	2.6 to 4.8
	Scenario	**Mean**	**Likely range**	**Mean**	**Likely range**
Global Mean Sea Level Rise (m)	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

6. Results

6.1 Mangrove Change Analysis

The changes in mangrove cover area are summarized below in the Table 5 and the decrease over the period is represented in the maps (Figures 6 and 7).

According to the temporal change analysis the forest area shows an overall increase of 1.104 ha between 1991 to 2013. Between 1991 and 2002 there is more gain than loss comparing to the period of 2002 to 2014 where there is more loss than gain.

Table 5- Mangrove change area between 1991 and 2013 in the Quirimbas National Park.

	Timeline		
Variables	**1991**	**2002**	**2013**
Area extent (ha^{-1})	11.244	12.812	12.348
Cover variation (gain and loss) (ha^{-1})	-	1.568	- 464
Annual loss percentage (%)	-	1.27	- 0.33

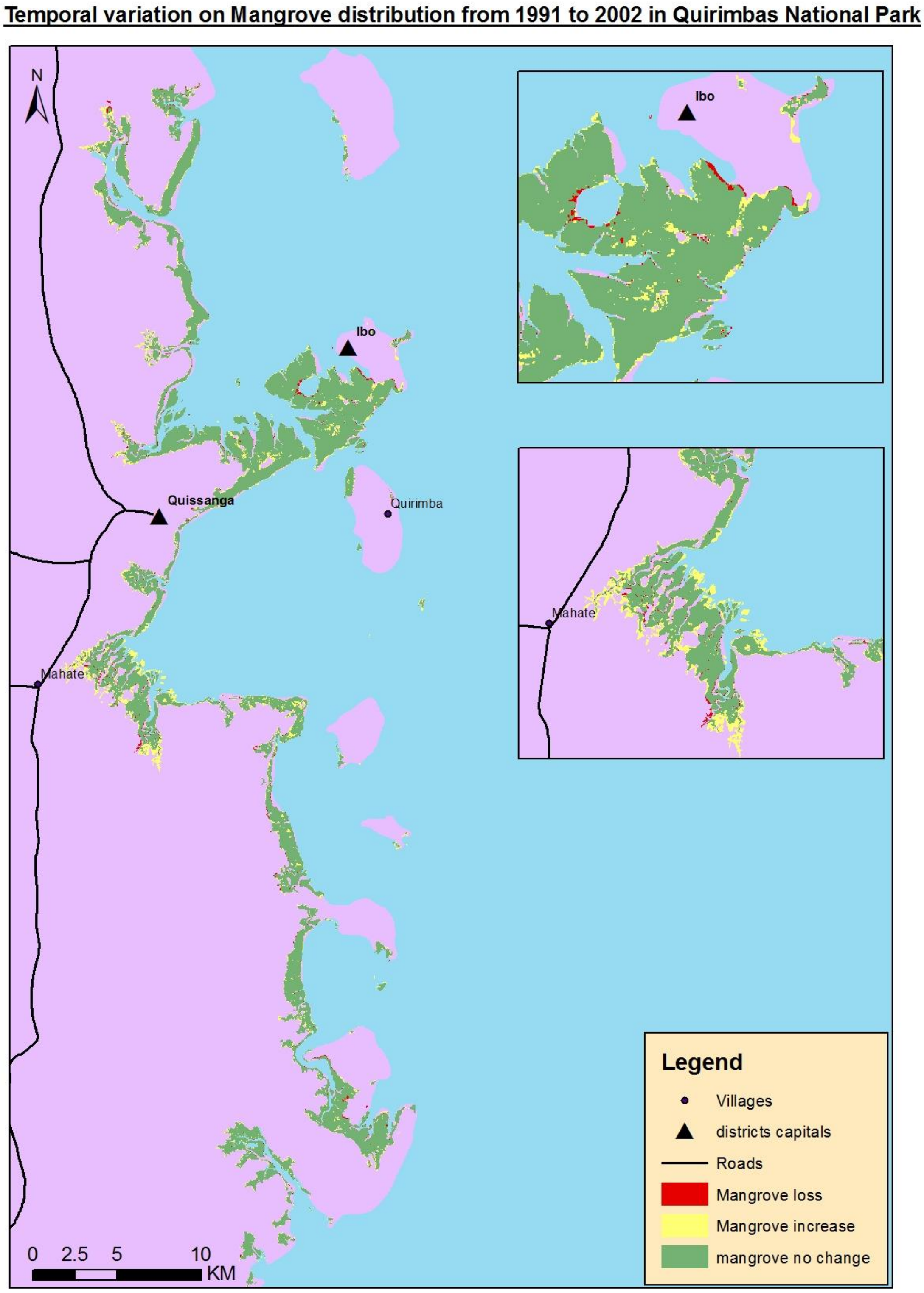

Figure 6– Mangrove change detection between 1991 and 2002 in Quirimbas National Park.

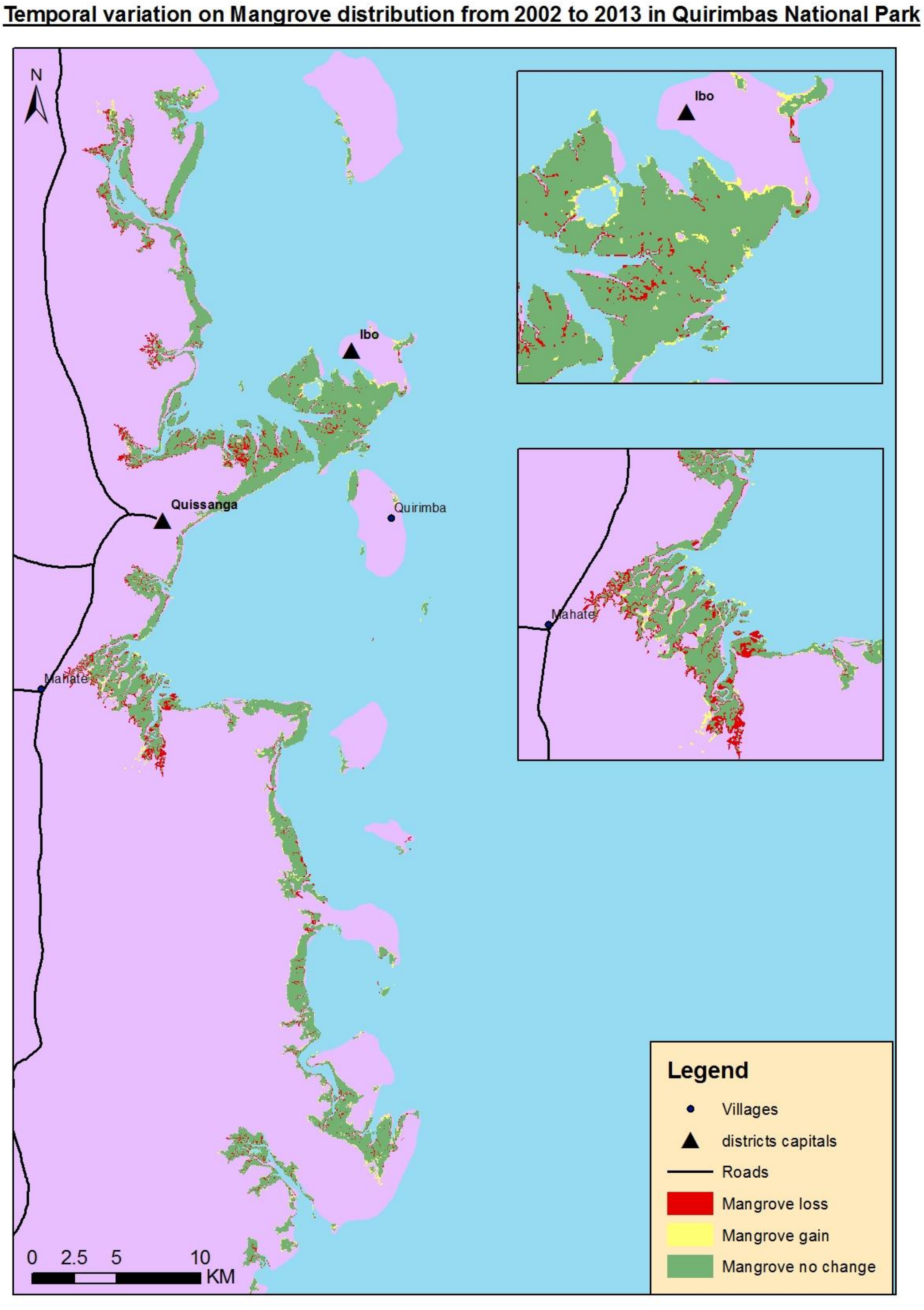

Figure 7– Mangrove change detection between 2002 and 2013 in Quirimbas National Park.

6.2 Mangrove Forest Structure

A total of 4.003 adult individuals were sampled in 3 sub-sampling areas (north, center and south) within the mangrove forests of QNP. A total of 6 species were found in the research area namely *Avicennia marina, Bruguiera gymnorrhiza, Ceriops tagal, Rhizophora mucronata, Sonneratia alba* and *Xylocarpus granatum*. *Xylocarpus granatum* was very rare (only few individuals sampled, not included on the statistical analysis) (Table 6). These species were distributed across the forest and no clear species zonation pattern was found.

According to the overall importance value index the most ecologically important species were *Rhizophora mucronata* and *Ceriops tagal* (Figure 8). Comparing the regions: in the north and south *Rhizophora mucronata* and *Ceriops tagal* had the highest values and in the center *Rhizophora mucronata* and *Sonneratia alba* had the highest values (Table 6).

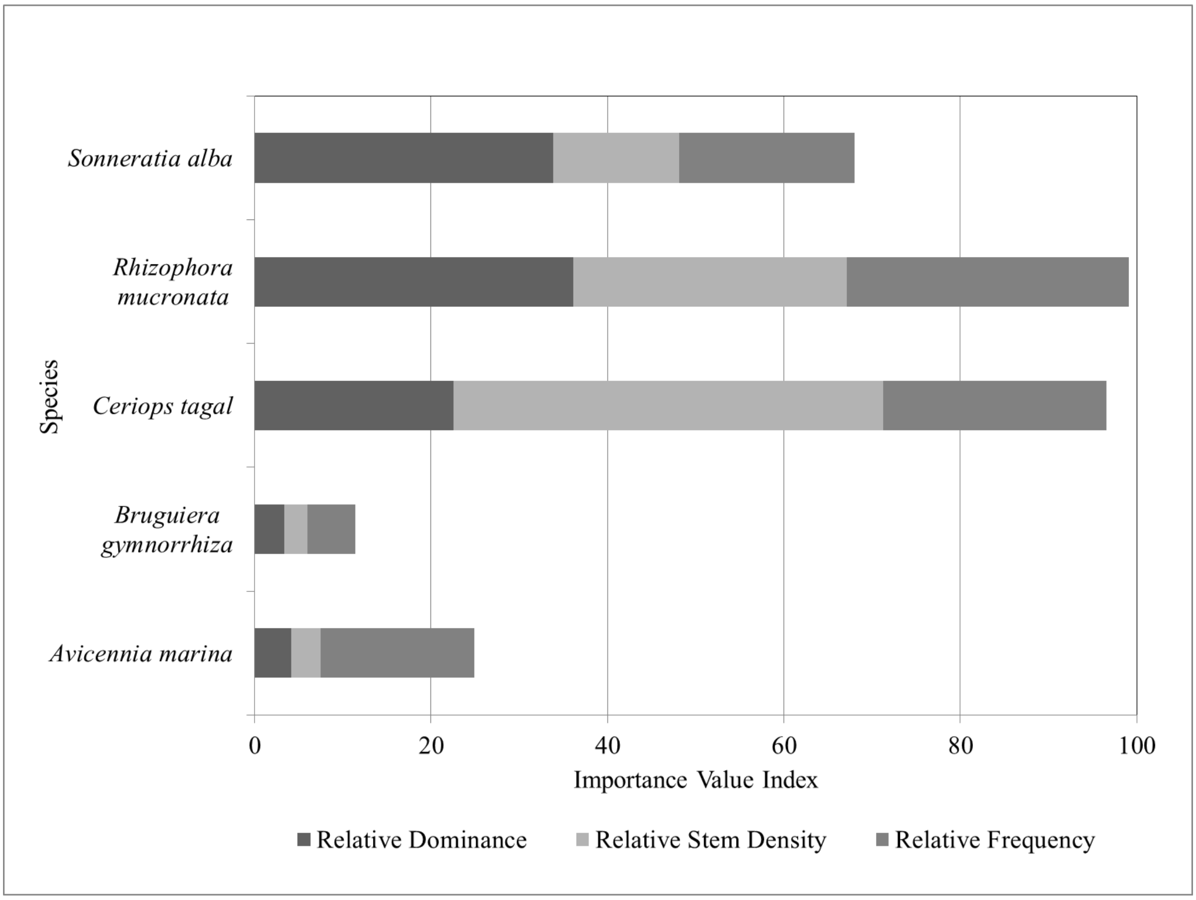

Figure 8– Importance Value Index of mangrove species on QNP.

The total density of individuals in the forest of the QNP was 579 stems ha^{-1}. The density per species show some variation, with 1.406 stems ha^{-1} for *R. mucronata*, 1.251 stems ha^{-1} for *C. tagal*, 393 stems ha^{-1} for *S. alba*, 338 stems ha^{-1} for *A. marina*, *80* stems ha^{-1} for *B. gymnorrhiza* and 8 stems ha^{-1} for *X. granatum.* There are significant differences in the stem density between species *($p<0.05$)*.

The basal area was lower among the species in the entire forest. The variation of complexity index is evident and tends to increase from north to south (Table 7). High levels of CI in center and south indicates specially the high basal area and height of the stands (Kairo *et al.*, 2001).

Table 6 - Importance value (IV) of the mangroves in the study sites considering 3 sub-sampling areas. All adult trees (2.5 cm diameter at breast height (DBH) within 0.01 ha plots were measured.

		Relative Values (%)			
Region	**Species**	**Dominance**	**Density**	**Frequency**	**IV**
North	*Avicennia marina*	4.15	3.32	17.47	24.94
	Bruguiera gymnorrhiza	3.32	2.69	5.42	11.43
	Ceriops tagal	22.57	48.7	25.3	96.57
	Rhizophora mucronata	36.14	31.01	31.93	99.08
	Sonneratia alba	33.82	14.27	19.88	67.98
Center	*Avicennia marina*	11.34	13.62	19.29	44.26
	Bruguiera gymnorrhiza	1.97	1.56	7.29	10.82
	Ceriops tagal	8.69	23.66	20	52.35
	Rhizophora mucronata	43.33	44.29	32.24	119.85
	Sonneratia alba	34.26	16.4	20.47	71.13
	Xylocarpus granatum	0.41	0.47	0.71	1.59
South	*Avicennia marina*	6.11	7.33	12.15	25.59
	Bruguiera gymnorrhiza	1.76	3.23	14.98	19.97
	Ceriops tagal	18.44	47.51	28.34	94.29
	Rhizophora mucronata	64.08	39.63	37.25	140.95
	Sonneratia alba	9.62	2.31	7.29	19.21

Nr of plots: North - 21, Center – 62 and South – 32. Total areas: North – 0.21 ha; Center – 0.62 ha and South 0.32 ha. Number of individuals sampled: North - 648, Center – 2040 and South -1315.

Structural attributes such as tree height, DBH, basal area, density and species composition were used to characterize mangrove community (Table 7). The mangrove forest is composed of relatively thin and short trees: the mean diameter of the forest was 7.69 cm and the height was 5.96 meters. The mean diameter did not vary significantly across the forest, being 9.42

cm, 8.29 cm and 9.61 cm in north, center and south respectively. Comparing the three areas there are no significant differences among the areas *($p>0.05$).* Despite the high diameter trees among the sampling areas, dwarf stands were commonly found in the forest within the highly saline grounds.

The mean height between areas was 5.69 meters, 6.88 meters and 5.68 meters respectively. Comparing areas there are no significant differences among the three areas *($p>0.05$).*

When comparing species, mean DBH (cm) ranged between 5.11 (Ceriops tagal) and 16.09 (*Sonneratia alba*), while mean heights varied between 3.41 meters (*Ceriops tagal*) and 8.22 meters (*Sonneratia alba*). The tallest trees observed were *S. alba* (8.22 meters), followed by *X. granatum* (7.96 meters) and *R. mucronata* (7.16 meters). Comparing species there are significant differences between species DBH and height *($p<0.05$).*

When comparing regions the highest DBH (cm) was observed in the south 16.09 (*Sonneratia alba*), and the tallest tree was observed in the center 8.22 meters (*Sonneratia alba*).

Table 7- Structural attributes of the mangroves in the research site considering the subsampling areas.

Region	Specie	Mean Diameter (cm)	Mean Height (m)	BA (m2 ha-1)	Stem Density (ha-1)	Nr of Species	CI*
North	*Avicennia marina*	12.64 ± 5.31	6.03 ± 2.08	2.73	102 ± 44	5	1.5
	Bruguiera gymnorrhiza	7.79 ± 3.10	6.50 ± 1.88	5.09	83 ± 56		
	Ceriops tagal	6.01 ± 0.22	3.17 ± 0.66	7.99	1.507 ± 599		
	Rhizophora mucronata	8.29 ± 1.40	6.52 ± 1.54	10.39	956 ± 291		
	Sonneratia alba	12.38 ± 3.01	6.23 ± 0.98	17.29	442 ± 295		
Center	*Avicennia marina*	8.61 ± 0.90	6.61 ± 0.93	5.18	452 ± 202	6	1.6
	Bruguiera gymnorrhiza	8.27 ± 1.48	6.51 ± 0.93	2.43	52 ± 21		
	Ceriops tagal	5.28 ± 0.67	4.80 ± 0.98	3.97	784 ± 264		
	Rhizophora mucronata	7.70 ± 0.73	7.16 ± 0.63	12.14	1.468 ± 275		
	Sonneratia alba	12.03 ± 1.00	8.22 ± 0.89	14.57	544 ± 206		
	Xylocarpus granatum	7.82 ± 0.00	7.95 ± 0.00	5.11	16 ± 16		
South	*Avicennia marina*	11.53 ± 2.81	6.21 ± 1.94	6.19	294 ± 252	5	2.2
	Bruguiera gymnorrhiza	7.21 ± 1.45	4.79 ± 0.59	1.19	130 ± 47		
	Ceriops tagal	5.11 ± 0.36	3.41 ± 0.23	6.79	1.908 ± 494		

Rhizophora mucronata	8.09 ± 1.08	6.02 ± 0.64	18.53	1.592 ± 336
Sonneratia alba	16.09 ± 1.91	7.96 ± 1.29	15.57	93 ± 50

*Complexity Index

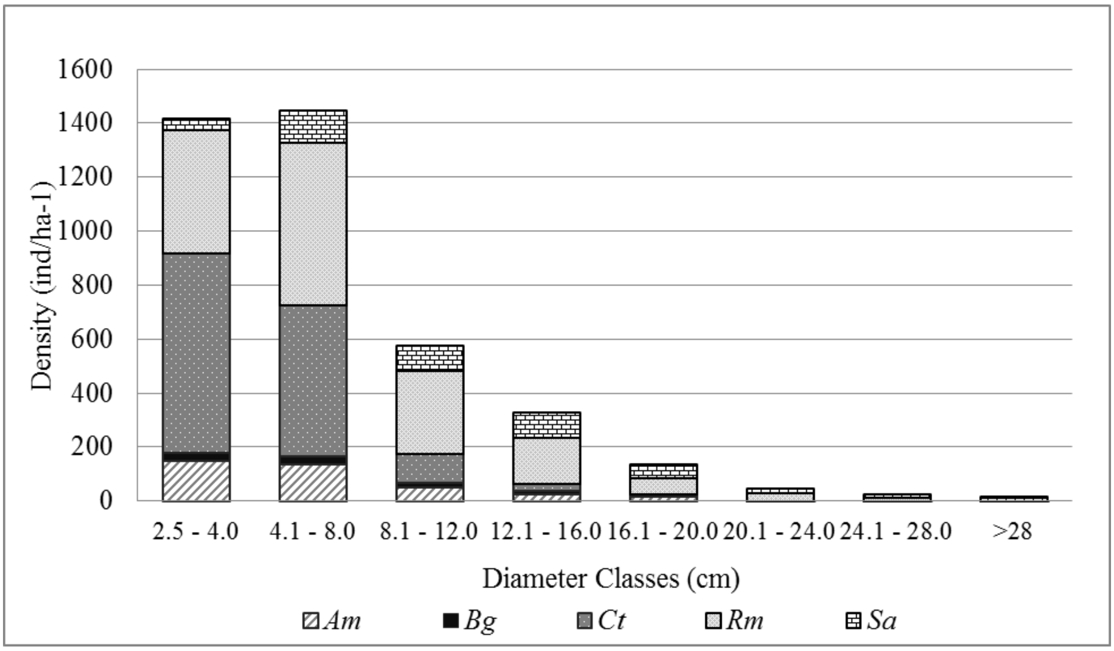

Figure 9– Species diameter distribution classes in in the QNP.

Figure 9 shows the diameter class distribution in QNP mangrove forest. The majority of trees were in the >2.5 – 8.0 cm size class. *Ceriops tagal* is characterised by a high number of individuals in lower size classes and *Rhizophora mucronata* has a high number of individuals in higher classes (8.1 – 20 cm). The diagram is indicative of selective harvesting or man-induced pressure in the size (8.1 – 12 cm) and (12.1 – 16 cm). The species that shows more evident signs of harvesting are *Ceriops tagal* and *Avicennia marina* (Figure 9).

The forest condition status is represented in the Figure 10. When compare to other categories (PC) partially cut (231 stems/ ha^{-1}), (SC) severely cut (395 stems/ ha^{-1}), (S) stump (188 stems/ ha^{-1}) and (DB) die back (171 stems/ ha^{-1}), the (I) intact stands had the higher mean density in the entire research area (941 stems/ha^{-1}).

There are statistical differences between average density of intact stands *($p<0.05$)* and other degradation categories (PC) partially cut *($p<0.05$)*, (SC) severely cut *($p<0.05$)*, (S) stump *($p<0.05$)* and (DB) die back *($p<0.05$).*

The cut categories (partially cut and severely cut) had highest densities in the south (225 stems/ ha^{-1}) and (395 stems/ ha^{-1}).

The degradation categories show a distribution pattern along the three regions and the entire forest as displayed in figure 12 below. A higher density of stumps was found in the north *Ceriops tagal* (636 stems/ ha^{-1}), while the highest die back was found in the south region *Ceriops tagal* (461 stems/ ha^{-1}).

In the north and center regions of QNP *Ceriops tagal* appeared as the preferred species for cutting whereas *Avicennia marina* appeared as preferred species for cutting in the south.

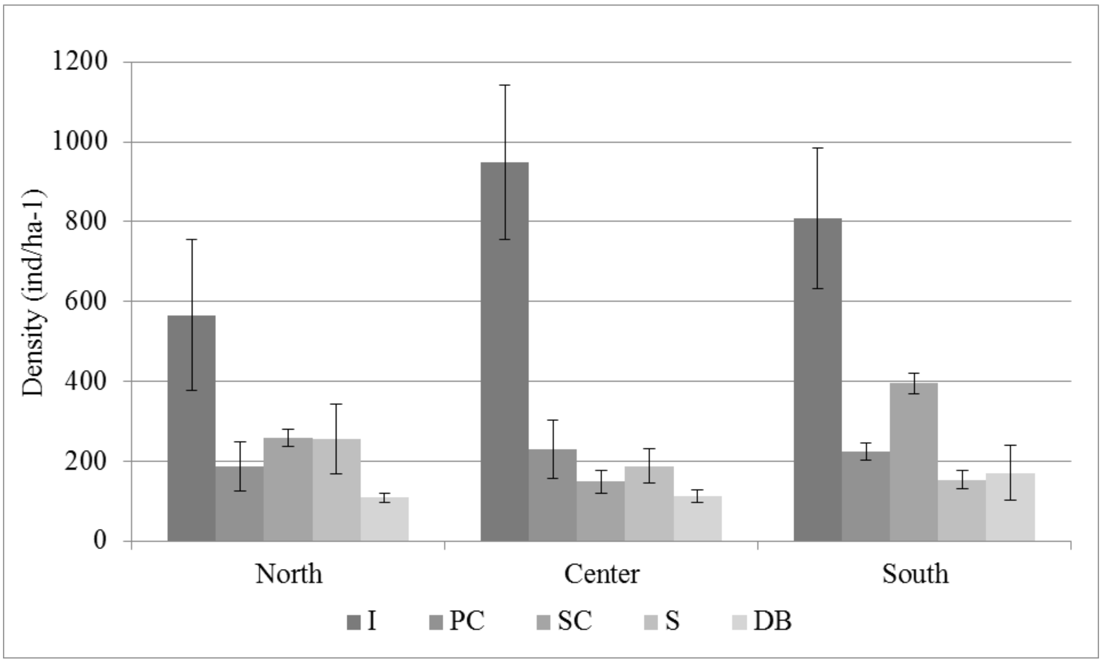

Figure 10– Mangrove forest conditions in the 3 sampling areas within the QNP. (I) Intact; (PC) partially cut; (SC) severely cut; (S) stump and (DB) die back.

Despite the high density of intact individuals (Figure 11), poles quality in the 3 subsampling areas (regions) confirms the existence of human-induced disturbance in the forest Figure 11).

Indeed, the density of straight poles is low when compared to semi-straight and crooked, which indicates selective logging. In general, the research area has the same distribution of intact poles and crooked poles. The highest density of semi-straight poles (880 stems/ha^{-1}) was found the center region (Figure 11), while the southern region accounted for the highest density of straight poles and crooked (504 stems/ ha^{-1})

and 639 stems/ ha^{-1}, respectively). These differences however are not statistically significant *($p<0.05$).*

Statistical differences were found when comparing *($p<0.05$)*: *Ceriops tagal* (1093 stems/ ha^{-1}) and *Rhizophora mucronata* (469 stems/ ha^{-1}) had the higher density of suitable poles for construction (straight poles). Moreover, the semi-straight poles (1073 stems/ ha^{-1}) the most crooked poles (658 stems/ ha^{-1}) were found in the *Ceriops tagal* and *Avicennia marina.*

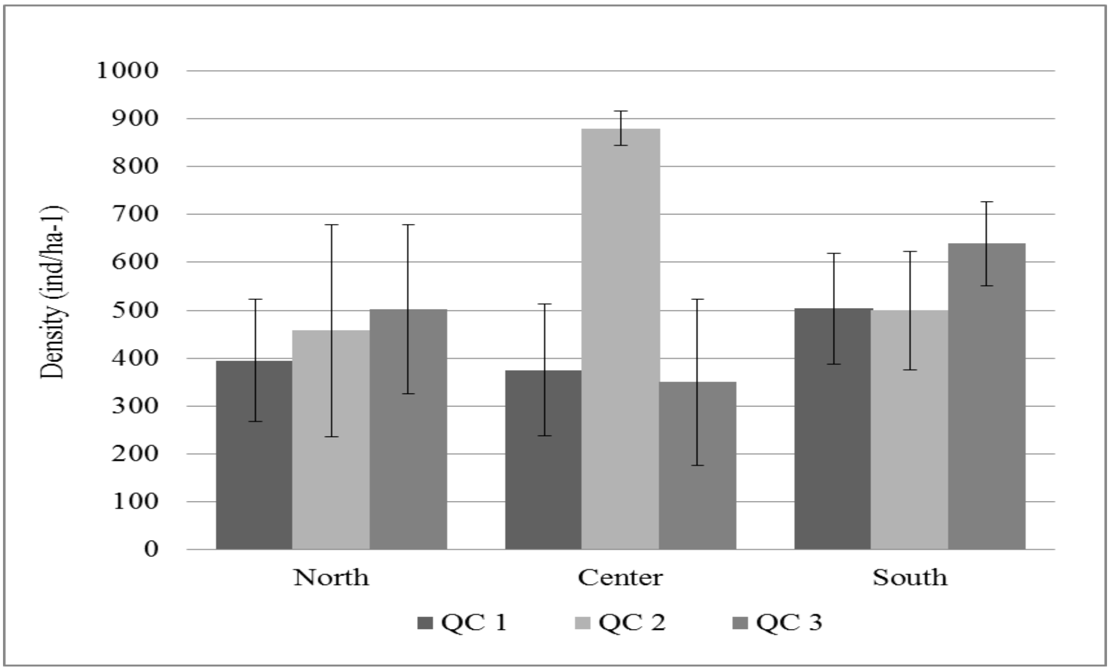

Figure 11 – Mangrove forest quality poles in the 3 sampling areas (regions). QC1 – represents most straight poles suitable for building and QC 2 - represents poles that need some modification prior to use in construction, while QC 3 represents crooked poles unsuitable for construction (Kairo et al., 2001).

6.3 Regeneration

Significant regeneration was observed in the research area. On average total juvenile regeneration ranged from 36.733 – 126.133 individuals/ha-1, with *R. mucronata* representing the higher density 180.400 density/ha^{-1} (Table 8).

Table 8 - Juveniles density (saplings ha^{-1}) in QNP. Regeneration class (RC).

5Region	Species	Density ha^{-1}			Total Density ha^{-1}
		RC I 0 - 40 cm	RC II 40.1 - 150 cm	RC III 150.1 - 300 cm	
North	*Avicennia marina*	1.333	1.700	1.067	4.100
	Bruguiera gymnorrhiza	0	0	700	700
	Ceriops tagal	32.800	4.267	6.667	43.733
	Rhizophora mucronata	3.867	11.800	28.200	43.867
	Sonneratia alba	233	300	100	633
	Total	**38.233**	**18.067**	**36.733**	**93.033**
Center	*Avicennia marina*	32.667	400	1.700	34.767
	Bruguiera gymnorrhiza	400	633	3.900	4.933
	Ceriops tagal	42.600	9.500	13.000	65.100
	Rhizophora mucronata	50.267	72.233	57.900	180.400
	Sonneratia alba	200	300	500	1.000
	Total	**126.133**	**83.067**	**77.000**	**286.200**
South	*Avicennia marina*	4.667	400	400	5.467
	Bruguiera gymnorrhiza	200	200	300	700
	Ceriops tagal	66.033	26.267	42.300	134.600
	Rhizophora mucronata	28.367	18.700	14.433	61.500
	Sonneratia alba	233	0	0	233
	Total	**99.500**	**45.567**	**57.433**	**202.500**

In general, there are more juveniles of RCI comparing with RCII and RCIII (Table 8). However, there were no observed statistical differences among the categories *($p<0.05$).* There is no indication of *B. gymnorrhiza* regeneration (RCI and RCII) and *S. alba* (RCII and RCIII).

The higher total juveniles density was observed in the central (286.200 individuals/ha^{-1}) and southern parts (202.500 individuals/ha^{-1}), while the north had less than half their densities (93.033 individuals/ ha^{-1}).

When comparing species, the highest density was observed in *Rhizophora mucronata* (180.400 juvenile/ha^{-1}) and *Ceriops tagal* (134.600 juvenile/ha^{-1}) followed by *Avicennia marina* (34.767 juvenile/ha^{-1}), *Bruguiera gymnorrhiza* (4.933 juvenile/ ha^{-1}) and *Sonneratia alba* (1.000 juvenile/ ha^{-1}). When comparing regions, there were significant differences between species within regions *($p>0.05$).*

The regeneration ratios RCI: RCII: RCIII were 1:2:1 for north, 1:1:1 for center .and 2:1:1 for south. The regeneration did not reach the effective rate of stocking 6:3:1 for juveniles as described from Kairo *et al.* (2002).

However, we can consider a potentially good regeneration capacity in QNP taking in consideration the seedling densities. Examining the trend across the regions, the center and south present the same pattern. In the meantime, the north shows more disturbance on regeneration probably related to the more accentuated anthropogenic pressure in these areas.

6.4 Climate Change Scenarios and Vulnerability

The below diagrams show the monthly average variation of climate elements precipitation (mm) and average of maximum and minimum temperature (ºC) within the QNP for the periods of mid-century (2050) and late-century (2070).

In the diagrams, current climate data (2015) is represented by climate data and the projections for mid-century (2050) and late-century (2070) are represented by the four scenarios (rcp 26, 45, 60 and 85).

All scenarios show moderate decreases in rainfall and a consistent extension of the dry season is well identified for QNP in the mid-century (2050) and late-century (2070) (Figures 12 and 13).

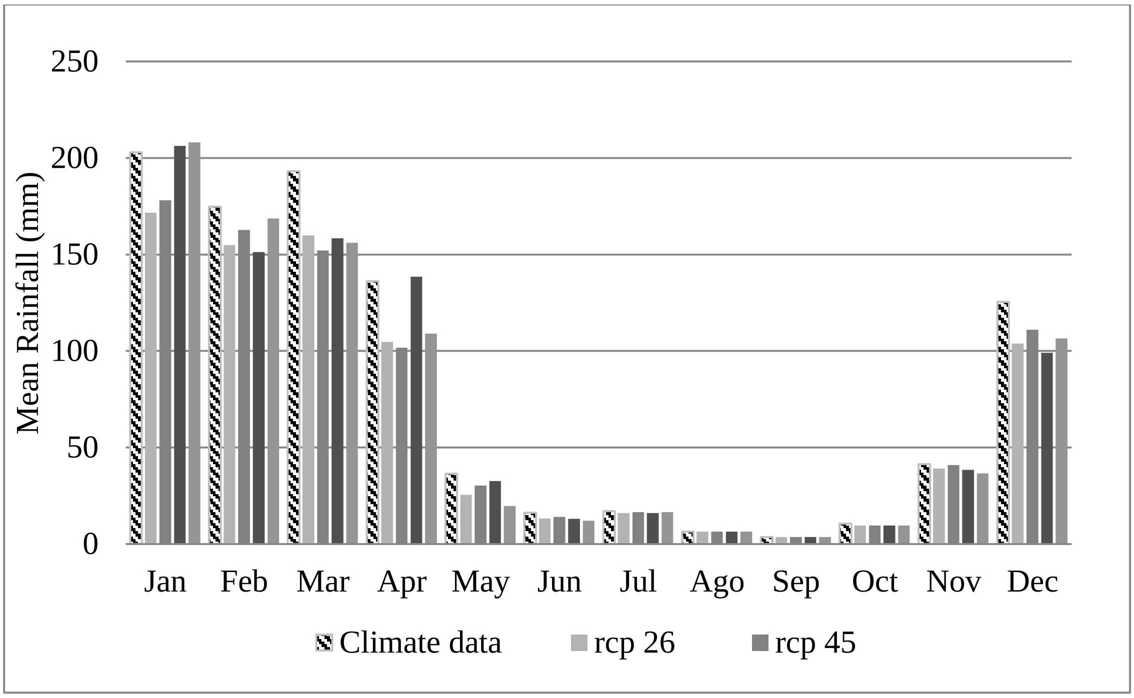

Figure 12 - Seasonal variation of mean rainfall in Mozambique for 2015 projections for 2050.

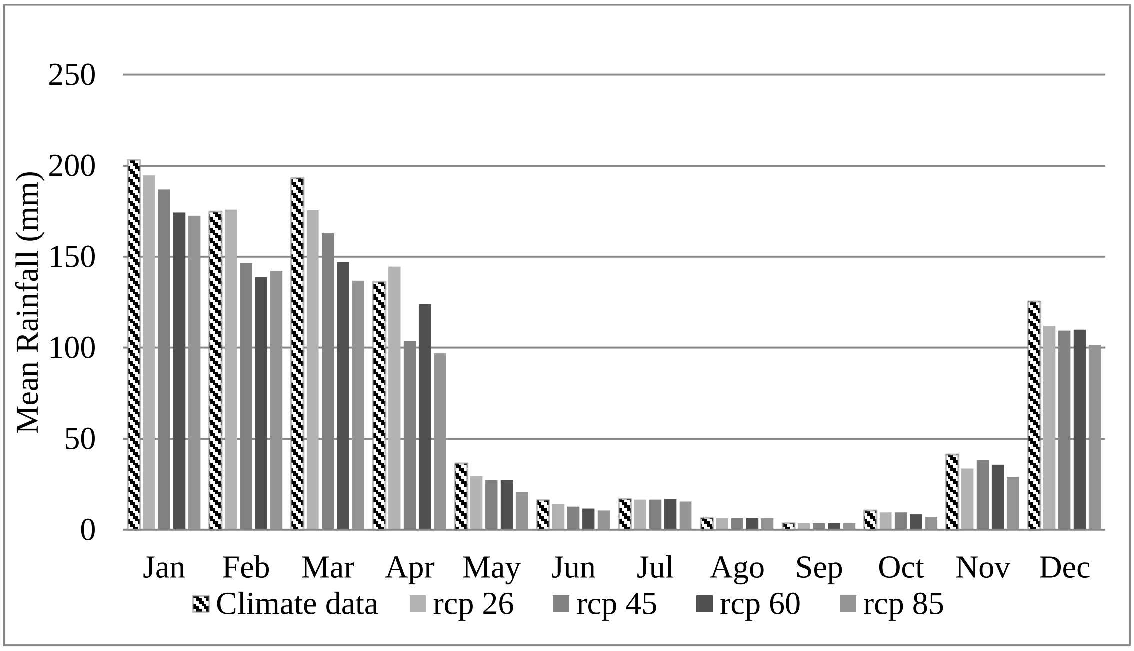

Figure 13 – Seasonal variation of mean rainfall in Mozambique for 2015 projections for 2070.

The below diagrams show monthly variation for maximum and minimum temperatures (ºC) for the periods of mid-century (2050) and late-century (2070). For 2050 both maximum and minimum temperatures show a monthly increase in average of 1.3ºC (Figures 14 and 15).

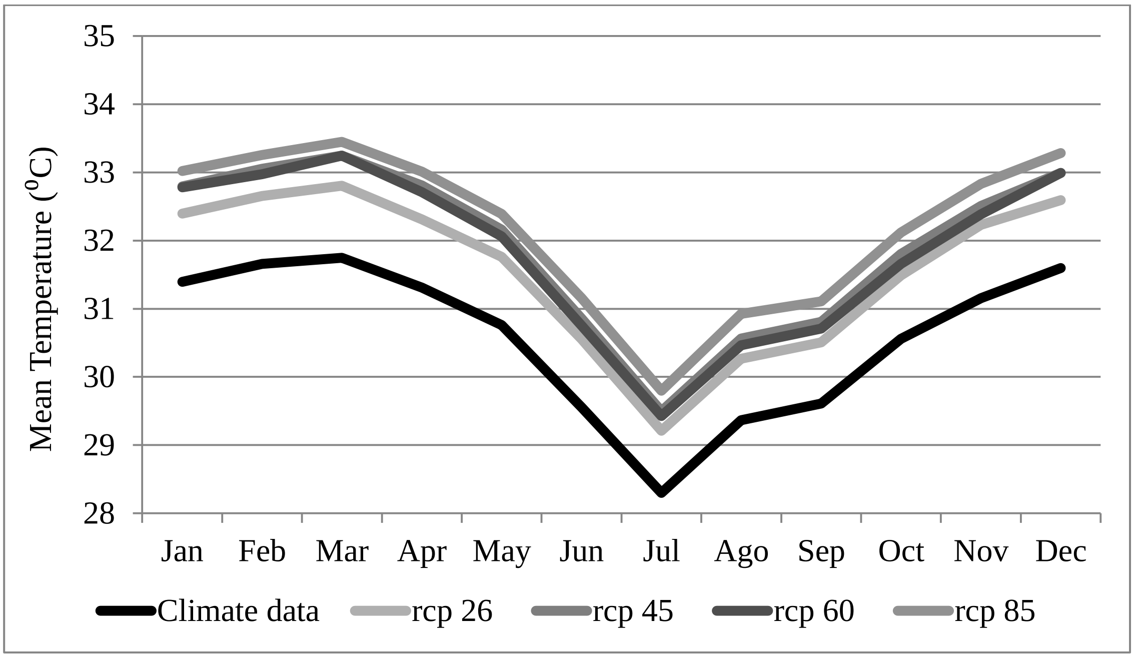

Figure 14 - Seasonal variation of maximum temperature (^{0}C) in Mozambique for 2015 projections for 2050.

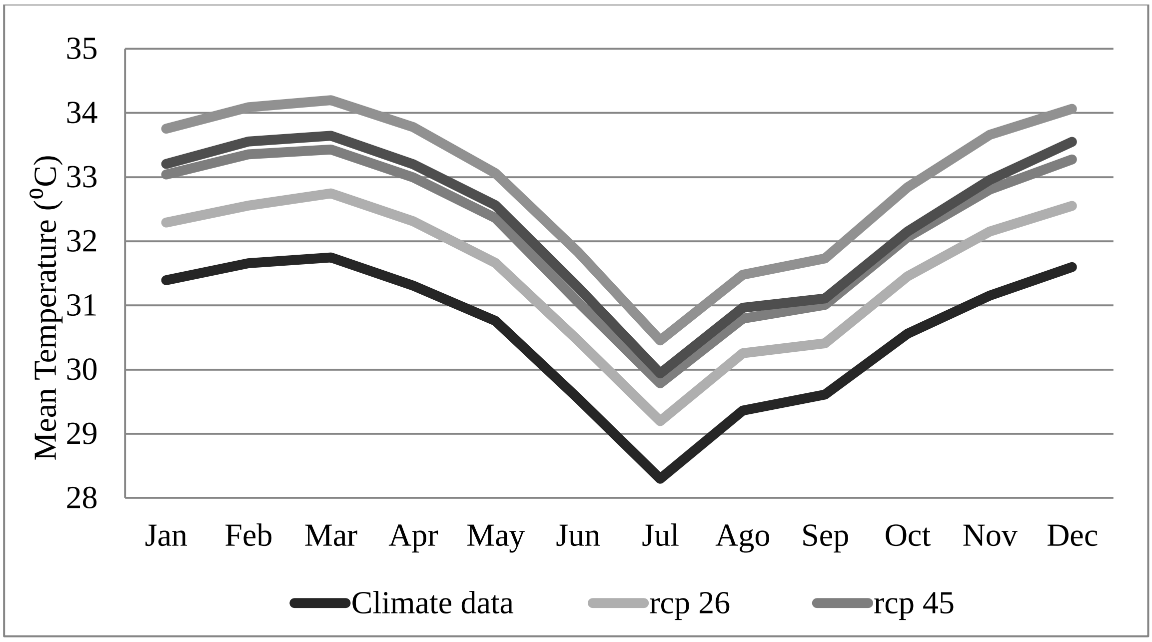

Figure 15 - Seasonal variation of minimum temperature (^{0}C) in Mozambique for 2015 projections for 2050.

The trend for maximum and minimum temperature (ºC) in QNP for 2070 shows an increase of temperature for all models in 1.6ºC respectively (Figures 16 and 17).

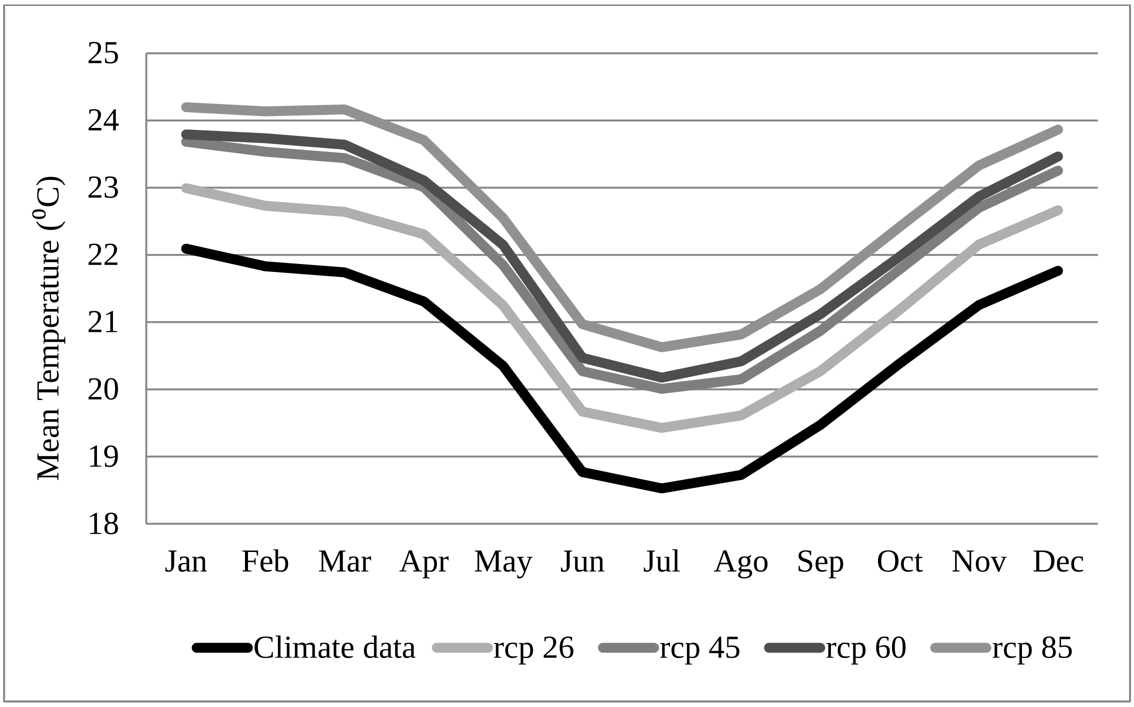

Figure 16 – Seasonal variation of maximum temperature (^{0}C) in Mozambique for 2015 projections for 2070.

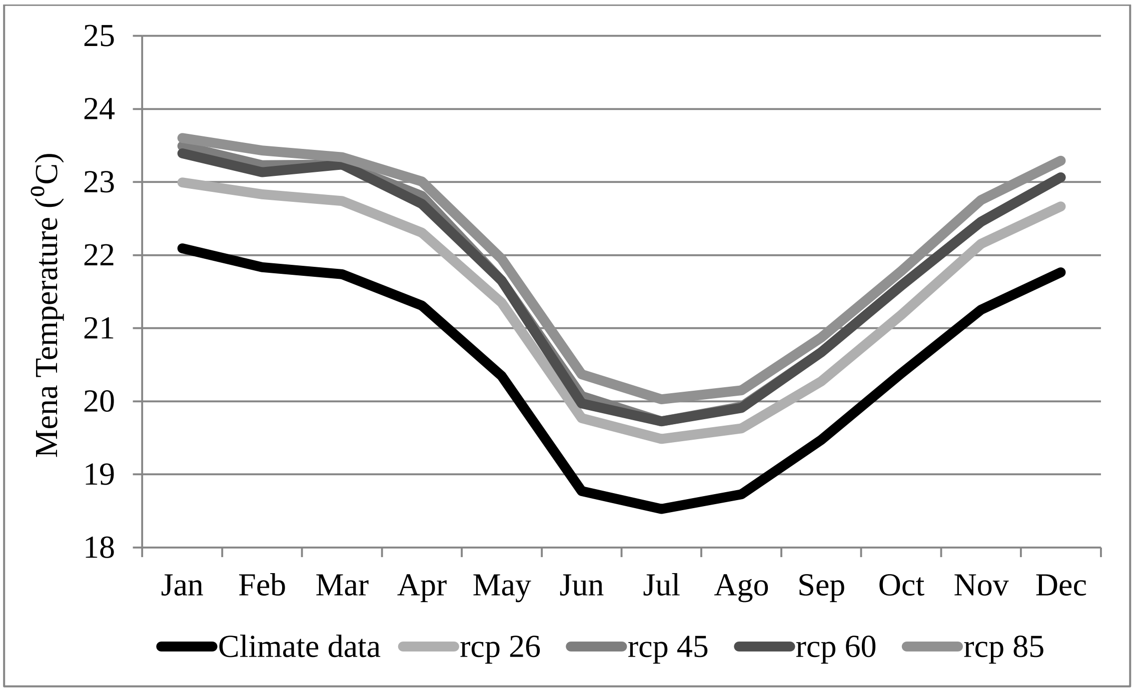

Figure 17 - Seasonal variation of minimum temperature (^{0}C) in Mozambique for 2015 projections for 2070.

7. Discussion

7.1 Mangrove mapping and forest structure

From the current temporal analysis an overall increase in mangrove cover was observed in QNP (Table 5). However between 2002 and 2013 a decrease in cover area of 464 ha representing 0.33% per year was estimated for this forest. Despite being a negative fact, it is distinctively lower than the average of 0.7% per year estimated for Kenyan mangrove forests (Kirui *et al.*, 2012) and that of 1-2% per year for global degradation rate of mangrove forests (Giri *et al*., 2011).

Similar results of increase or low decrease of mangrove in Cabo Delgado province between 1991 and 2002 were reported by Fatoyinbo *et al.* (2008) and Ferreira *et al.* (2009). This stability in forest area is probably due to the difficulty of access, low population density and absence of major natural environmental changes (Fatoyinbo *et al.*, 2008). The slight decline observed after 2002 can be related to multifactors such as the coastal vulnerability, the increase of pressure on mangroves and population growth in the coastal districts (INE, 2013).

Mohamed *et al.* (2008) and Palling *et al.* (2008) describe the mangrove forest structure alterations as a combination of cumulative and complex interactions between landscape position, rainfall, hydrology, sea level, sediment dynamics, subsidence, storm driven processes and human disturbance. However, it is difficult to isolate the singular effect of each factor in a complex mangrove system.

The demand for timber resources, the population growth within the QNP (INE, 2013) and illegal logging might have influence on the harvesting pattern with no sustainable incentives for local community. At the Ibo, Situ Islands and Mussemuco local retailers have been selling mangrove poles with DBH (4– 10 cm) for prices ranging from of 50 - 100 Mtn per pole in Pemba markets. There are also considerable demands of mangrove wood for the growing tourism industry in QNP, with operators showing preference for mangrove poles (indiscriminate of species) as building material, mostly for aesthetic reasons.

7.2 Regeneration

Natural regeneration was observed in the entire forest with high densities comparing to the data from Bandeira *et al.* (2009) and other mangrove forests in Kenya (Kairo *et al.,* 2002; Mohamed *et al.,* 2008). *R. mucronata* was evidently highly regenerating in the forest followed by *C. tagal* and *A. marina.* Very low regeneration of *B. gymnorrhiza* and S. *alba* was observed. This fact means that the regeneration depends largely on stand dominance species in conjunction with the structural characteristics and environmental conditions across the forest similarly to the findings of Mohamed *et al.* (2008).

Saplings were frequently found growing in clusters close to the mother tree, what gives the advantages in respect to predation, diseases and sedimentation (Bosire *et al.,* 2005).

We also observed high abundance of juveniles in smaller gaps and under high canopies rather than bigger gaps as observed by Mohamed *et al*. (2008). Gaps are generally characterised by increased light and temperature, high water evaporation rates (soil water and water from trees surrounding the gaps), and high pore-water salinity (Duke, 2001; Bosire *et al.,* 2005). These harsh conditions naturally select more capable species, and ultimately have influence on forest species composition (Bandeira *et al.,* 2009).

According to Duke (2001), forest canopy gaps are common in mangroves and usually result after disturbances such as selective harvesting and natural mortality of trees. This phenomenon can be related to the habitat heterogeneity due to disturbance and altered topography (Duke, 2001; Mohamed *et al*., 2008). Gaps created by selective harvesting of branches may recover over long periods (Ellis and Bell, 2004), thus specific management principles need to be developed to ensure that the diversity of the forest is maintained and gap recovery is fast enough to ensure the regeneration of the forest.

The success of mangrove recruitment and regeneration is also influenced by factors such as tides, temperature, sedimentation, soil stability and predation of propagules by crabs and colonization of seedlings by insects (Kairo *et al.,* 2001; Bosire *et al.,* 2008 and Bandeira *et al.,* 2009). All these processes can be altered by tree cutting and illegal logging (Kairo *et al.,* 2001; Bosire *et al.,* 2008).

B. gymnorrhiza and *S. alba* had lower regenerations, and many were visibly suffering from die back. This fact also contributes, in addition to lower densities of adult individuals, contribute to decrease regeneration rates (Bosire *et al.,* 2008).

7.3 Climate Change Analysis

Climate change might affect mangroves through the changes in sea level, floods, precipitation, temperature, extreme storm events and human impacts (Lovelock and Ellison, 2007; Gilman *et al.*, 2008; Ellison, 2010). However, climate change cannot be addressed as an isolated impact. Mangrove adaptation to climate change impacts should be addressed by an integrated examination of temporal analysis, forest structure and climate trends.

All these changes in the climate components are expected to affect mangrove growth and its spatial distribution (Field, 1995; McLeod and Salm, 2006; Gilman *et al.*, 2008; Ellison, 2010). High temperatures, variations in rainfall and sea level rise (SLR) in QNP will control mangrove distribution and resilience (Gilman *et al.*, 2008). Temperatures can lead to changes in species composition and phenological patterns (e.g., timing of flowering and fruiting) and increasing the expansion of mangroves. The projected consistent rainfall pattern will increase salinity and decrease growth and seedling survival, thus altering species composition through competition between mangrove species. Sea level rise will affect directly seaward mangroves, which in turn will migrate landward. Here, environmental conditions for recruitment and establishment of mangroves in new areas, including suitable hydrology, availability of water and sediment composition, will regulate competition with non-mangrove plant species (Krauss *et al.*, 2008). Erosion as a consequence of rising of sea level will result in weakened root structures and falling of trees and too high duration, frequency and depth of inundation (McLeod and Salm, 2006; Gilman *et al.*, 2008).

Mangrove vegetation zones have different levels of resilience, some zones being more resistant and resilient to climate elements, e.g. rising sea-level, the physiographic setting, sediment surface and presence of obstacles to landward migration, affects mangrove resistance (Lovelock and Ellison, 2007).

A large number of wide (DBH) dead trees were found along the shoreline area, along with visible substrate disaggregation and disturbance. Furthermore, severe erosion in the northern region of the Park added to already stressing conditions to the remaining trees and compromised a well succeeded regeneration. Opposite process, with similarly damaging results was observed in the south, where sediment accretion in shoreline also creates stressful conditions. Further reduction in the population density of trees at the shoreline would incur elevated risks of even higher erosion and no protection of the coastline from storm surges and similar events. Low lying areas, including the islands (Matemo, Ibo, Quirimba and Situ) and shoreline areas along the Park will definitely be affected.

Global precipitation patterns are expected to increase slightly with different spatial and timely distribution (Field, 1995; Houghton *et al.*, 2001; Lovelock and Ellison, 2007; Gilman *et al.*, 2008; Krauss *et al.*, 2008; INGC, 2009b; Ellison, 2010). However a consistently dry season is also predicted. The frequency of cyclones will increase (INGC, 2009b) and sea level rise is expected to reach 0.5 m in 2100 (Church *et al.*, 2004). The projected rainfall pattern will increase salinity and alter competition between mangrove species, resulting in reductions in mangrove area and changes in forest composition with possible increases in the extent of salt flats. According to Saintilan and Wilton (2001) and Ellison (2010), lower rainfall appears to assist mangrove encroachment into salt flats and it can lead to a change species distribution, dominance and growth.

High rainfall in association with the high sea surface temperatures in summer provides the heat to drive the formation and development of the cyclones (INGC, 2009b). Despite the localization of QNP in a moderate/low vulnerable coastline (Figure 2) strategic intervention a required to increase the resilience and ensure the adaptation to climate changes events.

Considering that since 1960, climate change effects are already present, the mangroves of QNP show some resilience to climate change. These impacts can be reduced by addressing human pressure and increase management actions for the critical areas (south and north regions). Restoration programs also can be addressed to increase the density of the mangrove belts in protection to the coastal events and ecosystem provision to the local communities. Potential areas were identified (e.g. center region – Quissanga village and south – Arimba) as suitable area for nursery establishment and restoration areas.

It is important to note that a large number of cut trees were found inside the forest. Probably the local community leave them uncut for protection along the coastline. In interviews with local communities they demonstrate some knowledge about the importance of mangroves for coastal protection against extreme events associated to climate change.

7.4 Scientific Climate Change Gaps

Climate change is a highly complex phenomenon with lack of empirical understanding (Murdiyarso *et al.*, 2012). In the last decades significant scientific interests emerged to understand the relationship between mangroves and climate change. Field (1995) studied the impacts of expected climate change on mangroves. Kelly and Adger (2000) illustrate the relationship between access to secure flows of mangrove ecosystem services and societal vulnerability in Vietnam. Kathiresan and Rajendran (2005) assessed how coastal mangrove forests mitigate the effect of tsunamis, demonstrating how they can provide affective barriers against wave action during climatic events. Gilman *et al.* (2008) review the threats to mangroves from climate change and adaptation options. Donato *et al*. (2012) assess carbon stocks in the tropical Pacific as a tool to promote conservation and upland restoration. UNEP (2014) review the importance of mangroves in a document entitled "The importance of mangroves: a call to action" and Sierra and Kintz (2015) assessed ecosystem-based adaptation for improving coastal planning for sea-level rise in: a systematic review for mangrove coasts.

More information has been developed but there are critical gaps in studies accounting for ecosystem benefits that occur in locations distant to the ecosystems in consideration, such as the benefits that offshore fisheries derive from mangrove ecosystem and the mangroves dynamics versus the climate change and human induced impacts. More studies are needed to understand mangroves dynamics, the responses to climate changes and factors that support them to overcome expected changes and human interventions (McLeod and Salm, 2006).

The climate change impacts on mangroves will not occur in isolation; anthropogenic threats to mangroves are expected to increase with climate change. The response of mangroves to climate change will be a result of these impacts acting synergistically.

In Mozambique some studies were developed on mangroves forest assessment such as the reports of Barbosa *et al.* (2001), Bandeira *et al.* (2009) and Ferreira *et al.* (2009). Regarding to climate change and mangrove conservation Government of Mozambique through the INGC developed the assessment of Impact of Climate Change on Disaster Risk in Mozambique (INGC, 2009ab) and INGC (2012). Lately the National Strategy for Climate Change (2012) and the new Conservation Law for Mozambique (16/2014) were approved.

Despite the high quality information produced in these studies, there are scientific gaps related to mangroves and climate change in Mozambique and specifically for QNP. Effective management programmes for conservation, rehabilitation and sustainable utilization of mangrove resources requires baseline information to build-up on. This study will contribute to the scientific knowledge of mangroves in Mozambique and provide technical information for the QNP Authorities for climate change mitigation through the information produced of mangrove extent area, forest condition, degraded areas and regeneration status (GIS coordinates of sampling plots can be used for forest monitoring). The change analysis (GIS evidences of forest decline) can also be used as a tool to improve local knowledge and set up restoration activities and monitor future variation on mangrove extent area.

8. Mangrove Adaptation Strategy

An affective adaptation strategy for QNP will result from a consolidated analysis of all ecosystems within the Park. Particularly for mangroves, the adaptation to climate change will require a number of actions in the QNP. Below are the main interventions:

8.1.1 Reduction of non-climate stressors (Human-induced factors)

Reduction of non-climate stressors increases the resilience of habitats and species to the effects of climate change and variability (Ellison, 2012). Knowledge about the importance of mangroves is not enough to ensure an effective management of mangroves. Raise awareness and education of community members needs to be effective and a crucial part of the monitoring of the QNP Management Plan to improve the sustainable use of mangrove resources, reduce direct human impacts and build capacity to adapt to climate change.

Effective actions have to be undertaken by the direct-dependent communities and the QNP Authorities in order to increase the resilience and ensure long-term benefits from mangroves. The direct-dependence can be related to fishery resources, timber for construction, fuelwood and coastal protection. These activities can be carried out by promoting long term partnerships with local NGOs, promote local capacity-building workshops, mangrove assessments including local community members, promote local committees for resources management and build the spirit of ownership of mangroves conservation through intensive campaigns demonstrating the mangrove importance using illustrative diagrams, maps and explicative posters (Figure 15).

Successful initiatives have been developed worldwide, e.g. WWF has worked with communities in Tikina Wai, Fiji Islands since late 1990s to establish three community mangrove reserves. These reserves are checked by village monitors and managed by a marine resource committee with representatives from six villages. Another example in Cameroon, where the local communities depend on mangrove wood as a fuel for cooking, smoking seafood and to provide poles for construction. Mangrove wood gathering zones for specific community needs have now been designated, particularly excluding mangroves that are on or near the seaward edge or on the margins of creeks and waterways.

Based on the cover change analysis (Figures 6 and 7) there are particular areas along the QNP affected by overexploitation of mangrove resources or suffering natural erosion and sedimentation. These areas are often located close to village areas or fishery centers (Arimba, Quissanga, Quirimba, Ulombo and Mussemuco). These areas should be prioritized as priority areas and promote adequate rehabilitation to protect the villages from storms, floods and sea level rise. Due the high pressure in Quissanga and Arimba and the large number of population living close to mangroves, these areas can be selected as pilot areas for restoration of mangroves involving the local communities.

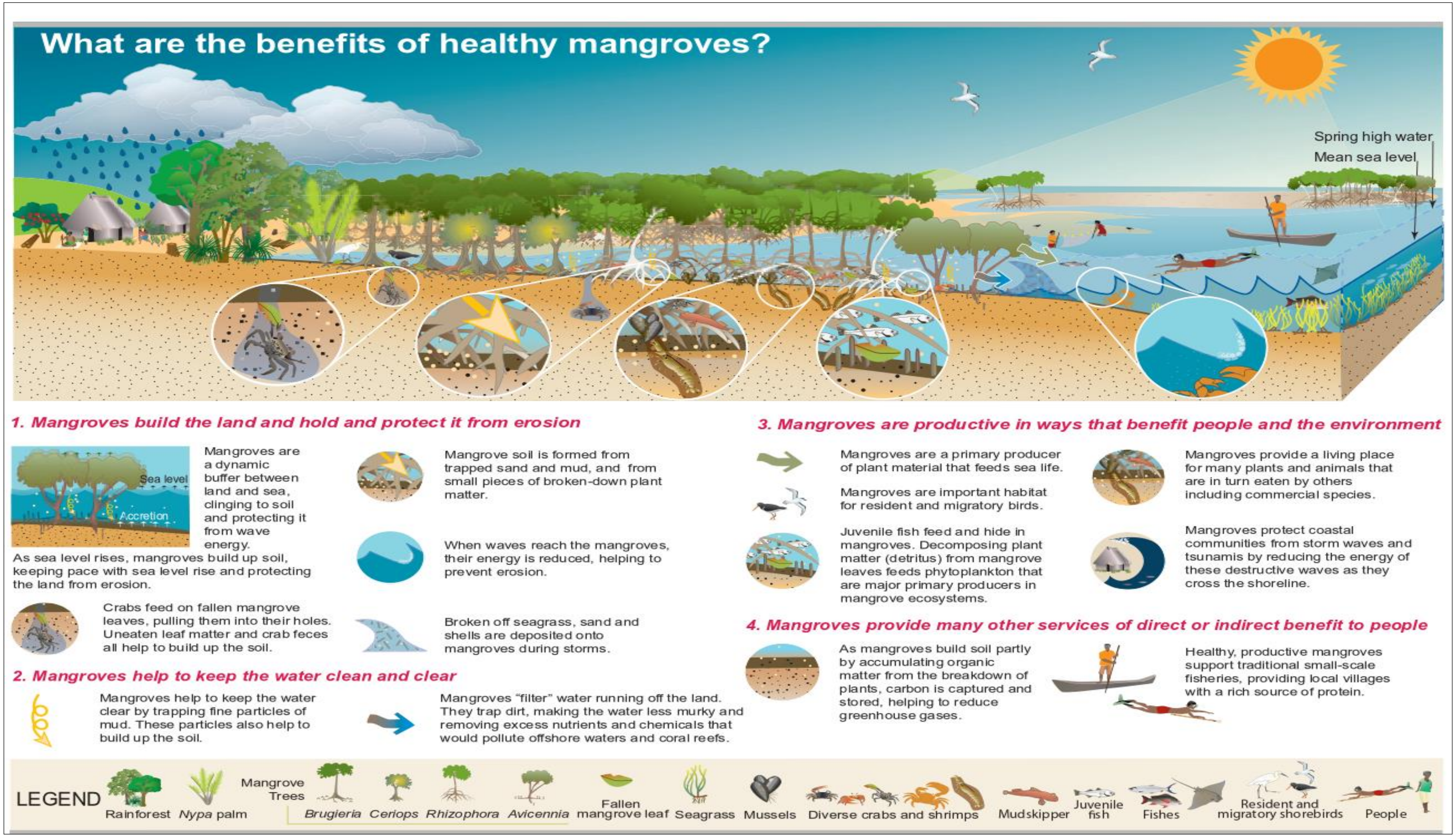

Figure 18 – Demonstration diagram of the benefits of healthy mangroves (Ellison, 2012).

8.1.2 Legislation Enforcement

In Mozambique mangrove forests are protected by Law. However they have been managed under the general legislation related to the environment, fisheries, coasts or wetlands and often been neglected and their legal status not properly acknowledged or enforced. Despite the inclusion of mangroves in national level, the legislation should be enforced at the local level (District level, Park Authorities and local communities). In Mozambique, there is a lack of Governmental empowerment for mangrove conservation, forestry resources management, effective coastal planning development, restoration programs and awareness conservation campaigns of coastal ecosystems involving local communities (Chevallier, 2013).

The economic development related to exploration of natural resources has been increasing in Mozambique, particularly the new wealth from the exploration of oil, coal and gas. Cabo-Delgado is one of the richest provinces in terms of natural resources particularly oil and gas resources. The expansion of these sectors is likely to lead to increasing interactions and conflicts between stakeholders with fossil fuel interests and those concerned about the environment. QNP is located within of some target areas for gas exploitation and the impacts of these activities related to non-effective law enforcement might lead to environmental and social disturbances to the Park area.

There is often a lack of consideration of the impacts of upstream development on downstream mangroves (agriculture and changes in river flows). Wetlands such as mangroves are often used without zoning for different levels of usage and protection or monitoring of sustainable use.

A stronger Legal Framework for mangrove conservation should be created and implemented to set carbon projects and give the importance for mangroves and other potential high sequestration ecosystems (seagrasses and saltmarshes) that – are not currently incorporated into the national climate change emission reduction strategy for GHG inventory emissions.

There is a continuous need of building capacity related to mangrove vulnerability and adaptation in many Governmental management agencies and improve technologies to mitigate negative impacts of climate change and design and implementation of effective mitigation strategies. The QNP Management Plan (MITUR, 2014) mentions the importance of climate change impacts to mangroves within the Park and future mitigation actions. Park Authorities can play a vital role on mangrove conservation and climate change mitigation. QNP has a comprehensive zonation plan, so, based on the forest resources statement provided by this report a better community-based conservation plan can be negotiated with adjacent coastal communities – the key beneficiaries of mangrove goods and services – to ensure protection and enforcing their sustainable use.

Mangrove management should be integrated with a broader coastal management plan, taking into consideration the below approved Park zonation (MITUR, 2014):

1. *Total Protection Zone* on land as well as in the marine part (46% of the QNP);
2. *Specific Use Zones* on land (13% of QNP);
3. *Community Development Zones* on land and marine parts (41% of QNP);
4. *Buffer Zone* around the current limits of QNP.

Mangrove forests are distributed along these zoning areas (Figure 19) and a high number of cut trees were identified in all these specific zonation areas. Most of these areas have population living around mangroves forests and this suggests an effective implementation of the QNP Management Plan and promotion of conservation and sustainable use of mangrove resources involving local communities.

Local communities living in coastal belt zones (which include all islands and shoreline areas like (Ibo Island, Quirimbas, Arimba, Quissanga, Mussemuco and Ulombo) if properly oriented are able to manage and protect ecosystems and play a key role in restoration and climate change mitigation.

The fiscalization of natural resources exploitation within the Park also needs to be improved to ensure a better management of the illegal issues not only related to commercial fisheries but also related to mangroves illegal logging. The migrations of fisherman within the Park also should be monitored. Lack of technology and enough number of rangers are important factor for the non-efficient monitory of forest resources exploitation.

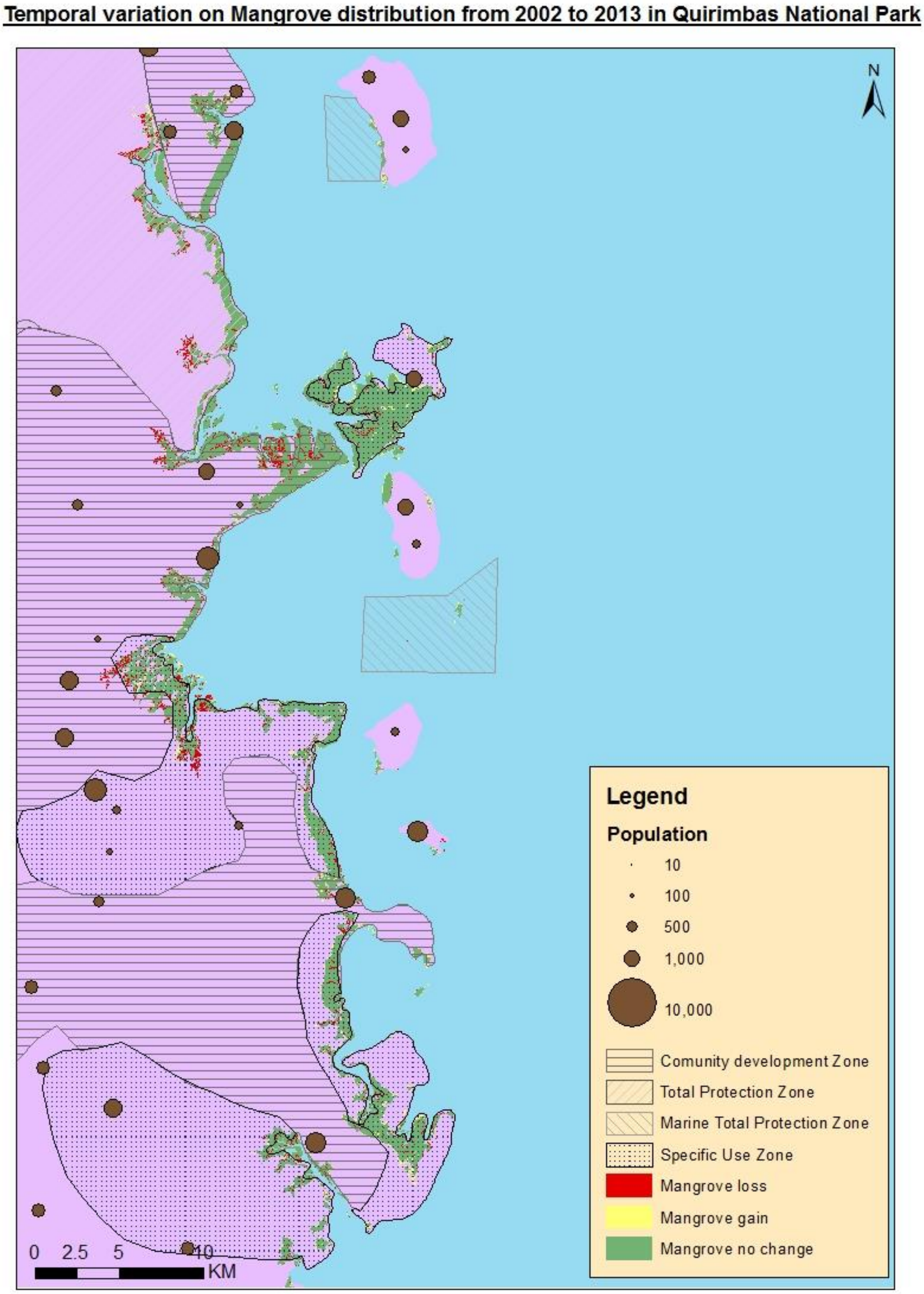

Figure 19 – Quirimbas National Park Management Plan and mangrove cover change between 2002 and 2013.

8.1.3 Effective Actions, Monitoring and Evaluation

8.1.3.1 Protect Vulnerable Mangrove Areas

To effectively reduce the risk of losing mangroves to climate change impacts such as sea-level rise, high rainfall variation and storms, Park Authorities should identify and protect vulnerable areas. Some areas with particular environmental characteristic are:

1. Protect critical areas (all islands along the QNP) naturally positioned to be more vulnerable to the climate change effects;
2. Establish greenbelts and buffer zones to allow for mangrove migration in response to sea level rise;
3. Promote sustainable use of mangrove in areas with high population numbers depending on mangrove resources (Ibo, Quissanga, Quirimba, Ulombo, Mussemuco and Situ Island).

Population growth within the Park is an important factor for the increase of pressure on mangroves. Human settlements should be reduced and not be permitted within 2 Km from the shoreline. Population should be encouraged to live behind the dense mangrove forest or other coastal vegetation in order to be protected against climate effects and to allow mangroves to migrate landwards.

Areas where suspended sediment is scarce, such as on oceanic islands mangroves may not even be able to keep up even with a much smaller sea-level rise (Ellison, 1993; Ellison, 2012). In the case of QNP the islands Ibo, Quirimbas, Situ and Matemo should have been included in the Management Plan for mangroves as vulnerable areas requiring a special plan for protection and restoration.

More integrated approaches for conservation of natural resources should be adopted, often referred to as ecosystem-based management (EBM) recognizing the importance and interplay of terrestrial, marine and coastal systems and the connectivity among the ecosystems e.g. mangroves and associated habitats like seagrasses, and coral reefs should be a priority activity within the Park (UNEP, 2011). QNP as a protected area can be a useful tool in implementing EBM by regulating different human uses in the area. It integrates all sectors that affect, or are affected by, land use change in coastal zones.

8.1.3.2 Rehabilitation of Degraded Mangrove Areas

Mangrove forests may recover without active restoration efforts (Ellison, 2012). When natural regeneration fails after discontinued anthropogenic pressure and the restoration process needs human intervention (active restoration), an understanding of the community ecology of the targeted mangrove species is necessary, e.g. its reproductive patterns, propagule dispersal, seedling establishment, zonation and hydrology (Bosire *et al.*, 2008).

Mangrove areas that are currently degraded should be restored (Figure 19). Community restoration programmes can be successful in restoring large numbers of mangrove trees. For example, in 1993 and 1995, at Gazi Bay, Kenya, more than 300.000 mangrove trees were planted in areas that were initially clear felled for industrial fuelwood (Kairo, 1995).

In southern Mozambique, Centre for Sustainable Development of Coastal Zones (CDS-ZC), also has a successful restoration project on the Limpopo River, where, with the involvement of local communities, a large number of mangroves where restored, after massive floods that devasted the mangrove forest.

Prioritized areas for community restoration in the QNP area likely to be in Quissanga, Ibo, Situ Islands and Mussemuco (Figure 19). Restoration of these areas may help create sustainable livelihoods for local communities and may also reduce the pressure on neighboring mangrove areas.

8.1.3.3 Restoration Activities using Smart Species

Understanding the ecology of local species is an important early step in successful mangrove restoration (Bosire *et al*., 2008), particularly in terms of choosing sites that have suitable hydrological regimes with respect to the frequency and duration of tidal flooding.

The greatest sensitivity of mangroves to climate change is to relative sea level that increases inundation periods. Sea level is projected to increase over the lifetime of mangrove trees. The most resilient or “smart “species to changing sea level within the QNP will be those with tolerance of a wider elevation bracket as *Ceriops tagal* and *Rhizophora mucronata* (Bosire *et al.*, 2008).

Once the restoration areas are identified and established, there are some restoration interventions that can be selected:

1. **Natural regeneration:** This is a no active approach that protects and monitors the mangrove area from the original stress and allows natural regeneration to occur. This approach does not usually involve rates that would result in rapid regeneration of the area, and it does not allow species selection.
2. **Direct propagule planting:** This approach involves active planting of mature mangrove propagules in areas where they might grow. The survival rate of seeds is usually much lower than with seedling planting.
3. **Seedling planting**: This approach involves active planting of seedlings in areas where they might grow. The seedlings can be obtained from wild sources elsewhere (wild seedling transplanting), or raised in a mangrove nursery.

For all this processes the success of the restoration should be monitored and it will include: monitoring the growth of replanted areas, assessing the mortality of seedlings and checking for human or natural disturbances.

An active restoration should take the steps described in the below flowchart (Ellison, 2012) into consideration (Figure 20).

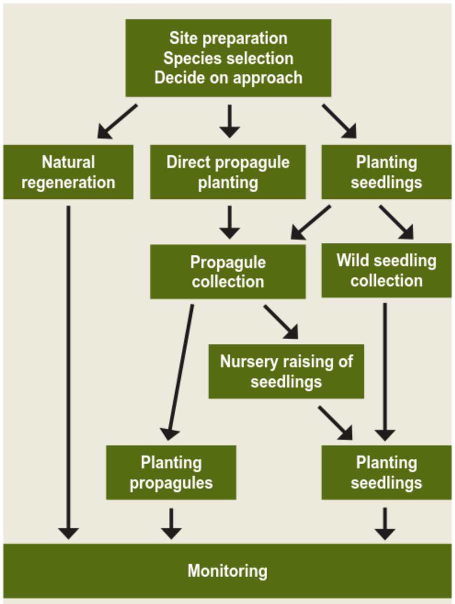

Figure 20 – Flowchart of restoration proposed by (Ellison, 2012).

8.1.4 Sustainable Alternative Livelihoods and Long-term Partnerships

Alternative livelihood options and diverse income opportunities allow communities to be flexible to adapt to social, political, and economic changes. Alternative livelihoods include charcoal production from coconut shells instead of mangroves as well as traditional honey harvesting and ecotourism on mangroves, encourages agroforestry, conservation and financial incentives to local communities.

Mangrove-dependent communities within the Park play an important role reducing in mangrove destruction, e.g. a successful initiative of mangrove restoration and conservation is the Mikoko Pamoja project in Gazy Bay, Kenya. In this project alternative he and Casuarinas plantations have been used as alternative wood resource. The project promotes mangrove conservation and carbon finance and provides financial incentives to local communities through job creations, livelihood increase (ecotourism and energy sources); community services provision (education, water and sanitation) and mangrove reforestation programme.

QNP needs a strong leadership and collaboration to mobilize support at local and regional level including Governmental Institutions and local NGO´s, national conservation groups and local communities to respond climate change impacts and promote sustainable use of resources and alternative livelihood for community needs.

8.1.5 Monitoring Mangrove Areas

There are uncertainties about future climate change, and how all the projected changes will affect mangroves ecosystems and humans. Ongoing monitoring could be the most important adaptive management activity of all. Management and monitoring of mangroves is best guided by information about mangrove extent and condition (Ellison, 2012).

These will be one of the most important actions to build resilience within the Park, particularly where sections of an otherwise healthy system are degraded. The following methods are the most useful for ongoing monitoring of climate change impacts:

1. Assess the mangrove extent and condition;
2. Establishment of permanent plots as we have done in the present study for (Monitoring, Reporting and Verification);

3. Sedimentation rates assessment and monitoring;
4. Relative sea level rise (SLR) assessment;
5. Hydrological assessment.

This document provides guidance to strategically prepare the park and mangroves forests to climate change impacts along with the local communities and adjacent ecosystems that most interact with it. As we know the Park area responds to climate change and other stressors, and new threats emerge while adaptation actions have not been implemented. It is important to actively use the results from this document and formulate an adaptation plan, to monitor and evaluate the Park success and to reassess and revise plans as new information emerges.

Repeat mangrove assessments will provide useful monitoring information on management success, needs and climate change impacts. Community involvement in monitoring process encourages information on mangrove condition to directly inform local management decisions.

In summary, important activities are necessary to support the monitoring such as: *Reduction of non-climate stressors*, such as human impacts, to improve health and condition of the existing mangrove forests; *protect habitats and rehabilitation of degraded mangrove areas*, protect vulnerable areas and seedlings, enhance accretion; *Law enforcement* for illegal logging reduction and effective coastal zone planning; *Influencing* upstream activities and operation to maintain fluvial sediment supply to the mangrove area*; Prohibition of sediment removal* or dredging from areas that are a source of sediment to mangrove areas; S*ustainable Alternative Livelihoods and Long-term Partnerships* to promote sustainable management of mangroves.

9. Conclusion

Mangrove forests of QNP are not pristine. This assessment revealed a low decrease of mangrove forest cover between 1991 and 2013. However, analyses of mangrove forest structure reflected a high disturbance related to human induced actions and climate change factors. Despite that, there was a clear evidence of healthy regeneration in this forest considering the high densities of juveniles; nonetheless the distribution of regeneration classes was not uniform suggesting a relation to the forest cover or harvesting areas.

The forest status and climate change impacts suggests an effective implementation of the Quirimbas National Park Management Plan specifically to address human induced impacts and climate change vulnerability. Several activities need to be carried out to ensure sustainable use of mangroves such as raise awareness of mangrove importance for marine habitats, ecosystem services assessment, protection of vulnerable areas, harvesting control, policy enforcement for illegal logging and promotion of a restoration programme involving the main stakeholders and local communities.

Policy makers also need to consider appropriate policies for mangroves and inclusion in initiatives to generate local incentives such as carbon trading/payment for ecosystem services.

10. Recommendations

The following recommendations are intended as guidance to ensure that the data and knowledge developed from this project will be used to support the QNP adaptation to climate change. These recommendations are also intended to avail project information to Park Authorities, researchers, or natural resource management professionals.

a) Inclusion of mangrove carbon assessment for the QNP[1]- mangrove ecosystem has good prospect in the storage of relatively vast amount of carbon which is an ecological service contributing for the climate change mitigation;

b) An assessment of hydrology dynamics in the QNP and sedimentation is required as well to understand the dynamic of this important ecosystem to understand the adaptation of mangroves

c) Establish Permanent Monitoring Plots – the plots used in this project can be used as a basis to select the permanent plots for monitoring locations; it would be possible to assess the change in forest composition and structure over time. The plot centers of each of the subplots within the selected plots should contain a permanent stake, and marking of the trees near plot center and corners;

d) Based on the information developed in this report, a future Restoration Programme for QNP should be designed and implemented.

[1] A carbon baseline study (terms of reference already approved) funded by the FFEM project was about to start in the QNP at the time of elaborating this report.

11. References

1. Abuodha, P. A. W. and Kairo, J. G. (2001). Human-induced stresses on mangrove swamps along the Kenyan coast. Hydrobiologia, 458: 255–265.

2. Adger, W.N., Agrawala,, S., Mirza, M. M. Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B. and Takahashi, K. (2007). Assessment of adaptation practices, options, constraints and capacity. In Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 717-743.

3. Alongi, D.M. (2002). Present state and future of the world's mangrove forests. Environmental Conservation, 29, 331–349.

4. Bandeira, S. O., Macamo, C. C. F. Kairo, J. G., Amade, F., Jiddawi, N. and Paula, J. (2009). Evaluation of mangrove structure and condition in two trans-boundary areas in the Western Indian Ocean. Aquatic Conservation: Marine and Freshwater Ecosystems,19: 46–55.

5. Barbosa, F. M. A., Cuambe, C.C. and Bandeira, S.O. (2001). Status and distribution of mangroves in Mozambique. South African Journal of Botany, 67: 393–398.

6. Bosire J. O., Kairo J. G., Kazungu, J., Koedam, N., Dahdouh-Guebas, F. (2005). Predation on propagules regulates regeneration in a high-density reforested mangrove plantation. Mar Ecol Prog Ser, 299:149–155.

7. Bosire, J.O., Kairo, J.G., Kazungu, J., Koedam, N. and Dahdouh-Guebas, F. (2008). Spatial and temporal regeneration dynamics in Ceriops tagal (Perr.) C.B. Rob. (Rhizophoraceae) mangrove forests in Kenya. Western Indian Ocean Journal of Marine Science 7(1): 69–80.

8. Cahoon, D.R., Hensel, P., Rybczyk, J., McKee, K., Proffitt, C.E., Perez, B. (2003). Mass tree mortality leads to mangrove peat collapse at Bay Islands, Honduras after Hurricane Mitch. J. Ecol, 91:1093–1105.

9. Church, J. A., White, N. J., Coleman, R., Lambeck, K. and Mitrovica, J. X. (2004). Estimates of the Regional Distribution of Sea Level Rise over the 1950–2000 Period. J. Climate, 17:2609–2625.

10. Cohen, R., Kaino J., Okello, J.A., Bosire J.O., Kairo, J.G. Huxham, M., Mencuccini, M. (2013). Propagating uncertainty to estimates of above-ground biomass for Kenyan mangroves: A scaling procedure from tree to landscape level. Forest Ecology and Management, 310: 968–982.

11. Dahdouh-Guebas F. and Koedam N. (2006b). Coastal vegetation and the Asian tsunami. Science, 311:37–38.

12. Dahdouh-Guebas, F., Hettiarachchi, S., Lo Seen, D., Batelaan, O., Sooriyarachchi, S., Jayatissa, L.P., Koedam, N. (2005b). Transitions in ancient inland freshwater resource management in Sri Lanka affect biota and human populations in and around coastal lagoons. Curr. Biol, 15:579–586.

13. Donato, D. C., Kauffman, J. B., Mackenzie, R. A., Ainsworth, A. and Pfleeger, A. Z. (2012). Whole-island carbon stocks in the tropical Pacific: Implications for mangrove conservation and upland restoration. Journal of Environmental Management, 97: 89 – 96.

14. Donato, D.C., Kauffman, J.B., Murdiyarso, D., Kurnianto, S., Stidham, M., Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. Nat.Geosci, 4:293–297.

15. Duke N. C., Meynecke, J. O., Dittmann, S., Ellison, A. M., Anger, K., Berger, U., Cannicci, S., Diele, K., Ewel, K. C., Field, C. D., Koedam, N., Lee, S.Y., Marchand, C., Nordhaus, I. and Dahdouh-Guebas, F. A. (2007). World without mangroves? Science, 317:41–42.

16. Duke, N. (2001). Gap creation and regenerative processes driving diversity and structure of mangrove ecosystems. Wetlands Ecology and Management, 9: 257-269.

17. Ellis, W. L. and Bell, S. S. (2004). Canopy gaps formed by mangrove trimming: an experimental test of impact on litter fall and standing litter stock in Southwest Florida (USA). J Exp Mar Biol Ecol, 311:201–222.

18. Ellison, J. C. (2012). Climate Change Vulnerability Assessment and Adaptation Planning for Mangrove Systems. Washington, DC: World Wildlife Fund (WWF). 142 pp.

19. Ellison, J. C. and Zouh, I. (2012). Vulnerability to Climate Change of Mangroves: Assessment from Cameroon, Central Africa. Biology, 1:617-638.

20. Ellison, J.C. (1993). Mangrove retreat with rising sea-level, Bermuda. Estuar. Coast. Shelf Sci, 37: 75-87.

21. Ellison, J.C. (2010). Proceedings of the ASEAN Conference on Biodiversity, Singapore. ASEAN Centre for Biodiversity, Laguna Philippines. 28 pp.

22. Eslami-Andargoli, L, Dale, P, Sipe, N. and Chaseling, J. (2009). Mangrove expansion and rainfall patterns in Moreton Bay, Southeast. Queensland, Australia. Estuarine, Coastal and Shelf Science, 85: 292–298.

23. FAO. (2007). The world's mangroves 1980-2005. FAO forestry paper 153. Rome.

24. Fatoyinbo, L. and Simard, M. (2013). Height and biomass of mangroves in Africa from ICESat/GLAS and SRTM. Int. J. Remote Sensing, 34(2):668-681.

25. Fatoyinbo, T. E., Simard, M., Washington-Allen, R. A. and Shugart, H. H.(2008). Landscape-Scale Extent, Height, Biomass, and Carbon Estimation of Mozambique's Mangrove Forests with Landsat ETM+ and Shuttle Radar Topography Mission Elevation Data. Journal of Geophysical Research, 113: 1–13.

26. Ferreira, M.A., Andrade, F., Bandeira, S.O., Carduso, P., Mendes, R. N. and Paula, J. (2009). Analysis of cover change (1995-2005) of Tanzania / Mozambique transboundary mangroves using Landsat imagery. Aquatic Conserv, 19:S38-S45.

27. FFEM. (2010). Climate change adaptation in the Quirimbas National Park, Mozambique. 75 pp.

28. Field, C. (1995). Impacts of expected climate change on mangroves. Hydro-biologia 295, 75–81.

29. Gilman E. L., Ellison, J., Duke N. C., Field, C. (2008). Threats to mangroves from climate change and adaptation options: A review. Aquatic Botany, 89:237–250.

30. Gilman, E. (2002). Guidelines for coastal and marine site-planning and examples of planning and management intervention tools. Ocean & Coastal Management, 45: 377–404.

31. Giri C., Ochieng E., Tieszen L., Zhu Z., Singh A., Loveland T., Masek J. and Duke N. (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography, 20:154 – 159.

32. Hijmans, R.J., Cameron, S. E., Parra, J. L., Jones, P. G. and Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology, 25: 1965-1978.

33. Hoguane, A. M. (2007). Diagnóstico da Zona Costeira de Moçambique. Revista de Gestão Integrada, 7(1): 69-82.

34. Houghton, J., Ding, Y., Griggs, D., Noguer, M., van der Linden, P., Dai, X., Maskell, K. (2001). Climate Change 2001: The Scientific Basis (Published for the Intergovernmental Panel on Climate Change).Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA.

35. Howard, J., Hoyt, S., Isensee, K., Pidgeon, E., Telszewski, M. (2014). Coastal Blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature. Arlington, Virginia, USA.

36. INE. (2013). Annual trends of total population of Provinces and districts 2007 – 2040. Available on: http://www.ine.gov.mz/estatisticas

37. INGC. (2009a). Synthesis report. INGC Climate Change Report: Study on the impact of climate change on disaster risk in Mozambique. [van Logchem B and Brito R (ed.)]. INGC, Mozambique. 48 pp.

38. INGC. (2009b). Main report: INGC Climate Change Report: Study on the impact of climate change on disaster risk in Mozambique. [Asante, K., Brito, R., Brundrit, G., Epstein, P., Fernandes, A., Marques, M.R., Mavume, A , Metzger, M., Patt, A., Queface, A., Sanchez del Valle, R., Tadross, M., Brito, R. (eds.)]. INGC, Mozambique. 321 pp.

39. INGC. (2012). Responding to Climate Change in Mozambique. INGC, Mozambique. 266pp.

40. IPCC. (2007). Climate change 2007: synthesis report. A report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

41. IPCC. (2013) Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

42. Kairo J. G., Lang'at, J.K.S., Dahdouh-Guebas, F., Bosire, J. and Karachi, M. (2008). Structural development and productivity of replanted mangrove plantations in Kenya. Forest Ecology and Management, 2670-2677.

43. Kairo, J. G., Dahdouh – Guebas, F. and Koedam, N. (2001). Restoration and management of mangrove systems — a lesson for and from the East African region. South African Journal of Botany, 67: 383–389.

44. Kairo, J.G. (1995). Community participatory forestry for rehabilitation of deforested mangrove areas of Gazi Bay (Kenya). A first approach. Final technical report. University of Nairobi, Department of Botany, Nairobi, Kenya.

45. Kathiresan K. and Bingham, B. L. (2001). Biology of mangroves and mangrove ecosystems. Advances in Marine Biology, 40: 81–251.

46. Kathiresan, K. and Rajendran, N. (2005). Coastal mangrove forests mitigate tsunami. Estuar. Coast. Shelf Sci, 65:601-606.

47. Kauffman, J. B., Heider, C., Cole, T., Dwire, K. A. and Donato, D.C. (2011). Ecosystem Carbon pools of Micronesian mangrove forests: implications of land use and climate change. Wetlands 31.

48. Kauffman, J.B. and Donato, D.C. (2012). Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. Working Paper 86. CIFOR, Bogor, Indonesia.

49. Kelly, P.M. and Adger, W.N. (2000). Theory and practice in assessing vulnerability to climate change and facilitating adaptation. Climatic Change, 47: 325-352.

50. Kirui, K.B., Kairo, J.G., Bosire, J., Viergever, K.M., Rudra, S., Huxham, M. and Briers, R.A. (2012). Mapping of mangrove forest land cover change along the Kenya coastline using Landsat imagery. Ocean and Coastal Management.

51. Komiyama, A., Poungparn, S. and Kato, S. (2005). Common allometric equations for estimating the tree weight of mangroves. Journal of Tropical Ecology, 21: 471-477.

52. Krauss, K.W., Lovelock, C.E., McKee, K.L., Lo´pez-Hoffman, L., Ewe, S.M.L. and Sousa, W.P. (2008). Environmental drivers in mangrove establishment and early development: A review. Aquat. Bot, 89:105–127.

53. Lovelock, C. E. and Ellison, J.C. (2007). Vulnerability of mangroves and tidal wetlands of the Great Barrier Reef to climate change. In: Johnson, J.E., Marshall, P. A. (Eds.), Climate Change and the Great Barrier Reef: A Vulnerability Assessment. Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Australia, 237–269pp.

54. Magris, R. and Barreto, R. (2010). Mapping and assessment of protection of mangrove habitats in Brazil. Pan-American Journal of Aquatic Sciences, 5(4):546-556.

55. Mavume, A. F. (2008). Tropical cyclones in the South-West Indian Ocean: intensity changes, oceanic interaction and impacts (PhD Thesis, accepted, Univ. of Cape Town, South Africa).

56. McIvor, A.L., Möller, I., Spencer, T. and Spalding. M. (2012a). Reduction of wind and swell waves by mangroves. Natural Coastal Protection Series: Report 1. Cambridge Coastal Research Unit Working Paper 40. Published by The Nature Conservancy and Wetlands International. 27 pp.

57. McIvor, A.L., Spencer, T., Möller, I. and M. Spalding. (2012b). Storm surge reduction by mangroves. Natural Coastal Protection Series: Report 2. Cambridge Coastal Research Unit Working Paper 41. Published by The Nature Conservancy and Wetlands International. 35 pp.

58. McLeod, E. and Salm, R. V. (2006). Managing Mangroves for Resilience to Climate Change. IUCN, Gland, Switzerland. 64pp.

59. McSweeney, C., New, M. and Lizcano, G. (2008). UNDP Climate Change Country Profiles – Mozambique. Available online at: http://country-profiles.geog.ox.ac.uk

60. MICOA. (2013). Estratégia Nacional de Mudanças Climáticas 2013-2025. 75pp

61. Mitsch, W.J. and Gosselink, J.G. (2007). Wetlands (Fourth edition). John Wiley and Sons, Inc. New York, USA. 582pp.

62. MITUR. (2009). Guidelines for tourism development in the QNP. Vol 1. 22 pp.

63. MITUR. (2014). Plano de Maneio 2013 - 2022: Parque Nacional das Quirimbas. Maputo.

64. MITUR. 2003. Plano de Maneio 2004-2008: Parque Nacional das Quirimbas. Maputo.

65. Mohamed, M. O. S., Neukermans, G., Kairo, J.G., Dahdouh-Guebas, F., and Koedam, N. (2008). Mangrove forests in a peri-urban setting: the case of Mombasa (Kenya). Wetlands Ecology and Management, 17 (3): 243-255.

66. Murdiyarso, D., Kauffman, J. B., Warren, M., Pramova, E. and Hergoualc'h, K. (2012).Tropical wetlands for climate change adaptation and mitigation: Science and policy imperatives with special reference to Indonesia. Working Paper 91. CIFOR, Bogor, Indonesia.

67. Page, S. E., Rieley, J. O. and Banks, C. J. (2011). Global and regional importance of the tropical peatland carbon pool. Glob. Change Biol, 17:798–818.

68. Paling, E.I., Kobryn, H. T., Humphreys, G. (2008). Assessing the extent of mangrove change caused by Cyclone Vance in the eastern Exmouth Gulf, northwestern Australia. Estuarine, Coastal and Shelf Science, 77:603 – 613.

69. Saenger, P. and Snedaker, S.C. (1993). Pantropical trends in mangrove above-ground biomass and annual litterfall. Oecologia, 96: 293-299.

70. Saintilan, N. and Wilton, K. (2001). Changes in the distribution of mangroves and salt- marshes in Jervis Bay, Australia. Wetlands Ecology and Management, 9:409–420.

71. Sierra-Correa, P. C. and Kintz, J. R. C. (2015). Ecosystem-based adaptation for improving coastal planning for sea-level rise: A systematic review for mangrove coasts. Marine Policy, 51: 385–393.

72. Solomon, S., Qin, D., Manning, M., Alley, R.B., Berntsen, T., Bindoff, N.L., Chen, Z., Chidthaisong, A., Gregory, J.M., Hegerl, G.C., Heimann, M., Hewitson, B., Hoskins, B.J., Joos, F., Jouzel, J., Kattsov, V., Lohmann, U., Matsuno, T., Molina, M., Nicholls, N., Overpeck, J., Raga, G., Ramaswamy, V., Ren, J., Rusticucci, M., Somerville, R., Stocker, T.F., Whetton, P., Wood, R.A., Wratt, D. (2007). Technical summary. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Inter-governmental Panel on Climate Change. Cambridge University Press,Cambridge, United Kingdom and New York, NY, USA.

73. Spalding M., Blasco F. and Field, C. (1997). World mangrove atlas. The International Society for Mangrove Ecosystems, Okinawa.

74. Taylor, M., Ravilious, C. and Green, E. P. (2003). Mangroves of East Africa. 24 pp.

75. Tobey, J., Rubinoff, P., Robadue Jr., D., Ricci, G., Volk, R., Furlow, J. and Anderson, G. (2010). Practical coastal adaptation to climate change: lessons from integrated coastal management. Coast Manage, 38:317–35.

76. Tomlinson, P. B. (1986). The Botany of Mangroves. Cambridge University Press: Cambridge.

77. UNDP. (2009). United Nations Development Progamme. An Appraisal of community vulnerability and adaptation to Climate Change in Mapai, Chicualacuala District, using the CRiSTAL Tool. Assessment Report.

78. UNEP. (2011). Taking Steps toward Marine and Coastal Ecosystem-Based Management - An Introductory Guide. 68 pp.

79. UNEP. (2014). The Importance of Mangroves to People: A Call to Action. van Bochove, J., Sullivan, E., Nakamura, T. (Eds). United Nations Environment Programme World Conservation Monitoring Centre, Cambridge. 128 pp.

80. Valiela, I., Bowen, J. and York, J. (2001). Mangrove Forests: One of the World's Threatened Major Tropical Environments. BioScience, 51: 807-815.

81. Vignola, R., Locatelli, B., Martinez, C. and Imbach, P. (2009). Ecosystem-based adaptation to climate change: what role for policy-makers, society and scientists? Mitig Adapt Strategies Glob Change, 14:691–696.

82. Walters, B.B., Ronnback, P., Kovacs, J. M., Crona, B., Hussain, S. A., Badola, R., Primavera, J. H., Barbier, E. and Dahdouh-Guebas, F. (2008). Ethnobiology, socio-economics and management of mangrove forests: A review. Aquat. Bot, 89:220-236.

83. Williams, M. J., Coles, R. and Primavera, J. H. (2007). A lesson from cyclone Larry: An untold story of the success of good coastal planning. Estuar. Coast. Shelf Sci, 71: 364–367.

APPENDIX 1

Table A 1 - Geographic coordinates of the sampling plots.

Plot nr	Latitude	Longitude
A3	40.486105	-12.395112
A7	40.560339	-12.598164
A8	40.502778	-12.334989
A9	40.500478	-12.210191
A10	40.494887	-12.457258
A11	40.564320	-12.662793
A12	40.610645	-12.759444
A14	40.536305	-12.531296
A16	40.560443	-12.400672
A17	40.575667	-12.729907
A18	40.500175	-12.285392
A21	40.555151	-12.532115
A23	40.561753	-12.389941
A24	40.502050	-12.244746
A29	40.536355	-12.763510
A31	40.488868	-12.476359
A32	40.564527	-12.672146
A33	40.581330	-12.722790
A34	40.475466	-12.287444
B4	40.465732	-12.269199
B5	40.469108	-12.399404
B7	40.487941	-12.400097
B8	40.474939	-12.404418
B9	40.541859	-12.397170
B12	40.567396	-12.714491
B13	40.501063	-12.308195

B16	40.486795	-12.470645
B19	40.580149	-12.753503
C35	40.604844	-12.372899
C36	40.470060	-12.342622
C1	40.508233	-12.342622

APPENDIX 2

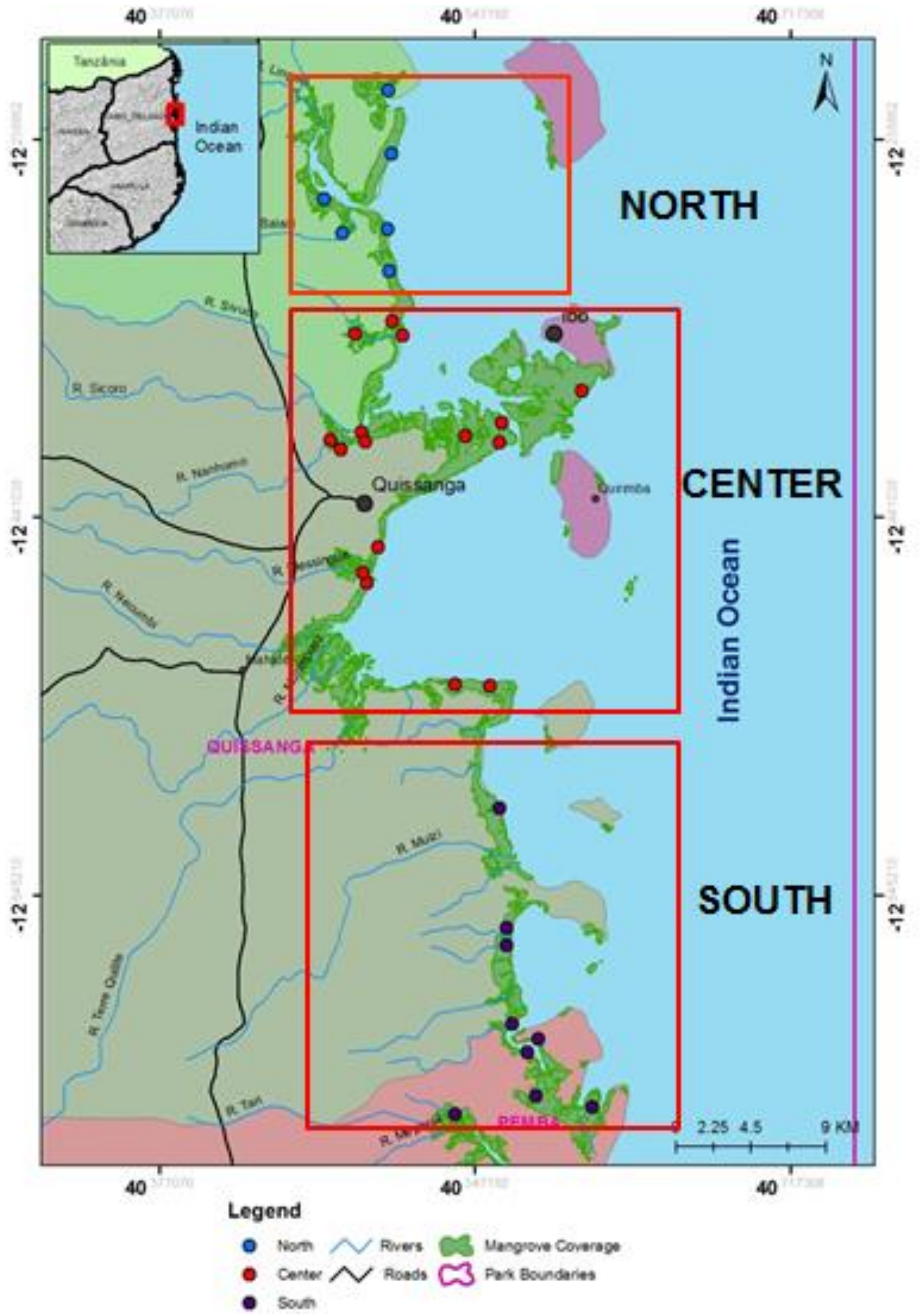

Figure A1. 1 – Sampling plots by regions (north, center and south) within the QNP.