THE EFFECT OF FOREST DEGRADATION ON FOREST STRUCTURE AND CARBON STOCK IN KIWENGWA PONGWE FOREST RESERVE, ZANZIBAR

NGWALI MAKAME HAJI

A DISSERTATION SUBMITED IN THE PARTIAL FULFILMENT OF THE
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ABSTRACT

This work reported in this dissertation was conducted in Kiwengwa-Pongwe Forest Reserve (KPFR) in Zanzibar. Specifically, the study assessed the forest structure, carbon stock and forest degradation. Eleven transects were laid out in the North – South direction and plots located along each transect. The distance between transects was 600 meters and plots were laid down systematically at intervals of 300 meters along each transect. Clusters of concentric circular plots of 5, 10 to 15 metres radius were established for measurement of diameter at breast height (dbh). The measured trees were grouped into the following classes: <4, 5-10, 11-20 and >20 cm. The forest had composition of 60 species in 52 families, Stand density of 281 stems ha^{-1}, Basal area of 5.75 m^2ha^{-1} and Volume of 33.97 m^3ha^{-1}. Biomass was 22.9 tha^{-1} with a Carbon stock of 11.5 $tCha^{-1}$. These results were slightly lower than earlier reported (1997) for the same forest, where volume and biomass then stood at 35.37 m^3ha^{-1} and 26.39 tha^{-1}, respectively. The mean Shannon & Wienner species diversity Index ranged from 0.83 at the forest edge to 1.74 at the forest centre, with a mean of 1.34, which is considered to be low to medium. Assessment of forest degradation showed removals of 159 stems ha^{-1} corresponding to a basal area of 2.6 m^2ha^{-1}, volume of 18 m^3ha^{-1}, carbon of 6.1$tCha^{-1}$ and CO_2 emission of 12tCO_2-e. These results indicated that KPFR is subject to degradation and hence a high potential for enhance carbon sequestration and storage through sustainable forest management. The study recommends that there is a need to upgrade the status of the surveyed forest reserve to improve its forest structure and carbon sequestration and storage potential.

DECLARATION

I, Ngwali Makame Haji, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

Ngwali Makame Haji Date
(MSc. MNRSA)

The above declaration is confirmed by

Prof. S. M. S. Maliondo Date
(Supervisor)

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LIST OF ABREVIATIONS AND SYMBOLS

AGC	Above-Ground Carbon
BA	Basal area
CBNRM	Community Based Natural Resource Management
Cm	Centimeter
CO_2	Carbon Dioxide
CO_2-e	Carbon Dioxide equivalent
DBH	Diameter at Breast Height (1.3m from the ground level)
DCCFF	Department of Commercial Crops Fruits and Forestry
FiNNIDA	Finish International Development Agency
GHG	Green House Gas
GPS	Geographical Positioning System
JFM	Joint Forest Management
km	Kilometer
KPFR	Kiwengwa Pongwe Forest Reserve
M	Meters
mm	Millimeter
NAFORMA	National Forest Resources Monitoring and Assessment
PNRM	Participatory Natural Resource Management
REDD	Reducing Emissions from Deforestation and Forest Degradation
SMZ	*Serikali ya Mapinduzi ya Zanzibar* (Revolutionary Government of Zanzibar)
TAFORI	Tanzania Forestry Research Institute
$tCha^{-1}$	Tones of Carbon per hectare per year
tCO_2-e	Tones of Carbon Dioxide Equivalent

UNEP	United Nations for Environmental Programmes
VCC	Village Conservation Committee
WCS	Worldwide Conservation Society

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Forest land in Zanzibar covers a total area of 265 292 hectares (about 26 % of the total land area) of which, Kiwengwa-Pongwe Forest Reserve (KPFR) accounts for 3323 hectares (DCCFF, 2008). The forest is managed by the Department of Commercial Crops, Fruits and Forestry (DCCFF) on behalf of the Government. The reserve is managed legally by part five (5) of the Forest Act Number 10 of 1996 of Zanzibar Government (GoZ, 1997). Natural forests are important natural resources in Zanzibar and contribute to poverty alleviation, protection of biodiversity and endangered species (DCCF, 2003). The role of tropical forests in climate change has assumed greater importance in international discourse, especially regarding the role of Reducing Deforestation and Forest Degradation (REDD) in climate change mitigation (IPCC, 2007). Accumulation of CO_2 in the atmosphere has implications on global climate change (Mackey *et al.*, 2008). Forests serve as carbon sinks by absorbing CO_2 and retaining it in organic form in forest biomass (Brown, 2003). Therefore forests act as “forest carbon reservoir” and affect the climate by reducing atmospheric carbon dioxide emissions (Brown *et al.*, 1997). The capacity of forests to serve as carbon sinks depends on forest structure, which in turn depends on the level of management, including level of forest conservation.

Forest structure is a broadly defined term relating to the physical arrangement, intermixing and composition and size distribution of trees and other components within stand and that it is fundamentally linked to ecological functions and processes (McElhinney *et al.*, 2005). It encompasses species composition; basal area, volume, biomass and carbon and their distribution of species and trees size (Husch *et al.*, 2002).

Forest structure is affected by deforestation and forest degradation. Deforestation means the loss of forests to a measurable sustained decrease in crown cover below 10-30 %, and/or is used to describe the process of removing trees by over cutting forests and converting the land to other uses (UNFCCC, 2006). Forest degradation refers to reduced forest quality and reduction in forest carbon and changes within the forest cover (from closed to open forest) (Vatn *et al*., 2009). "Depletion of forest to tree crown cover greater than 10 % is considered as forest degradation (FAO, 2003). It is estimated that deforestation and forest degradation contributes about 20 % of global CO_2 emission resulting from shifting cultivation, selective logging, under-storey, fires, fire wood harvesting, and are a substantial source of greenhouse emissions (Griscom *et al.*, 2009). Nevertheless, widespread forest degradation in developing countries remains poorly understood; therefore it is important to assess and quantify its impacts on forest resources (Niles *et al.*, 2001).

Assessments of the extent of tropical closed forests in Africa remain imprecise as only 36% of original closed canopy forest remains, but the current figures are not reliable (UNFCCC, 2008). According to IUCN (2005), West Africa has suffered severe deforestation; central Africa still has large forest blocks, but only some 59 % remains, whilst the total forest area in East Africa is low, with less than 10 % of original cover remaining. The forests in Eastern Arc Mountains and Coastal forests are recognized as biological hot-spots, centers of high diversity and centers of endemism but are under intense human population pressure (Burgess *et al.*, 2007). Coastal forest covered 70 000 hectares characterized by scattered patchy and thickets which are under intensive pressure of deforestation and forest degradation and having lost an average of 25 % over 15 years (FAO, 2004). Burgess *et al.* (2010) reported that the area of closed canopy forest in the Eastern Arc Mountains declined by 1 %, whereas coastal forests declined by 7 %. Recent deforestation rates estimated from 1990 to 2000 reported that Tanzania lost an average of 400 km^2 annually and over 35 % of the Eastern Arc forests have been lost between 1995 and 2000 (FAO, 2006). Zanzibar is currently losing an estimated 1.2 % of its forest each year (DCCFF 2003). The KPFR in Zanzibar is under severe threat of anthropogenic degradation from activities such as illegal fire wood collection and timber cutting (Makame, 2006).

The recently introduced 'Reducing Emissions from Deforestation and Forest Degradation' (REDD) mechanism is designed to offer opportunities for the protection of national forests reserve and biodiversity of the forest ecosystems (Baker *et al.,* 2010). It involves piloting and offering incentives such a variety of payment schemes to forest owners to manage forests through collaborative forest management strategies so that carbon sequestration is improved to mitigate climate change (Mackey *et al.,* 2008). Thus, information about the extent of forest degradation in relation to forest structure and carbon lost is important for planning and management of forests for sustainable development (Milledge, 2007). The aim of this study was to conduct a comprehensive assessment, analyze and report on the effect of forest degradation on forest structure and carbon stock in Kiwengwa Pongwe Forest Reserve in Zanzibar.

1.2 Problem Statement and Justification

Information on forest structure and effect of degradation is important for assessing the sustainability of the forest sector in Zanzibar. The inventory of woody biomass in Zanzibar Islands provided an excellent base line information for the forest resources in Zanzibar (Leskinen *et al*., 1997). Considering pressures exerted on tropical forests Zanzibar included, it is likely that the condition of forest has changed in the last 15 years, and therefore there is need for an update (UNFCCC, 2007). While natural forests in

Zanzibar are subject to both deforestation and forest degradation, so far there is no recent information on deforestation and less so on forest degradation. Makame (2006) and DCCFF (2004) reported on deforestation scenario but focused more on social economic aspects and did not assess forest degradation. Information on forest degradation is important for planning forest conservation and forest restoration (IUCN, 2005). Zanzibar biomass inventory of 1997 of KPFR by Leskinen *et al.* (1997) assessed the status of woody biomass in Zanzibar but did not assess the effect of forest degradation. Moreover, while Tanzania mainland is currently mapping its forest resources under NAFORMA, Zanzibar is yet to implement the same.

Therefore, this study is the first of its kind in Zanzibar, aiming at filling the information gap on forest degradation. A forest inventory was planned to establish base line information about the current status including the effect of forest degradation, forest structure and the carbon stock in KPFR. The results that will be obtained will help to establish sound baseline data and information on the extent of forest degradation and carbon stock lost. This information will be useful for the REDD initiatives and for general planning, policy making and implementation.

1.3 Objectives

1.3.1 Main objective

The main objective of this study was to assess the forest structure of natural forest in Zanzibar**.**

1.3.2 Specific objectives

The specific objectives of the study were to:

i. Assess forest structure and carbon stock in Kiwengwa Pongwe Forest Reserve
ii. Assess the effect of forest degradation on carbon stock in Kiwengwa Pongwe Forest Reserve

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Global Perspective on Tropical Forest Management

Management of tropical natural forests has for long time been vested in the central government with stronger emphasis on the sustainability principle, but with little emphasis on local community participation (FAO, 2006). Management of forest reserves and conservation has been taking place but, there is general failure of forest management in most developing countries due to poor governance and centralized approach of natural resource conservation (Bwalya, 2003). However, recent findings disclosed that traditional management approaches in conservation of tropical forests have failed due to increasing pressure of human activities that lead to deforestation and forest degradation (Hamilton, 1998).

Principle that has been revised include community empowerment, NGO engagement and good governance in the form of politically controlled neoliberal reform approach which has recently been modified to meet the seventh United Nation's Millennium Development

Goal on conservation for sustainable development (Atela, 2013). Despite those efforts, there are rapid change of forests due to increasing pressure of illegal tree cutting, wild fires, encroachment and farming. The consequence is forest degradation which leads to poverty, shortage of food, timber, fuel wood and climate change (Backeus *et al.,* 2006).

2.2 Ecological Characteristics of Natural Forests

A natural forest is a terrestrial ecosystem which is largely generated and maintained through natural ecological and evolutionary processes (Brendan *et al.*, 2008). Brendan, *et al.* (2008) suggested that natural forests are more resilient to climate change, more resistant and recover better from disturbances (fire, pests and disease), can adapt to new environmental conditions, and their carbon stocks have longer residency times. Pristine natural forests are forests that have not been disturbed by intensive human land-use activities including commercial logging (Mackey *et al.,* 2008). These authors further stressed that, understanding the role of natural forest in the biosphere and global climate system is critical and is an essential part of the global carbon cycle that has played, and continues to play a major role in regulating concentration of atmospheric greenhouse effect. They insisted that the carbon stored in aboveground living biomass of trees in natural forest is typically the largest pool and the most directly impacted by deforestation and forest degradation.

Forest structure has big influence to remove CO_2 from the atmosphere and store in different parts of trees and forest soils (Gurney *et al.,* 2008). Therefore, protecting carbon storage in natural forest structure is essential part in climate change mitigation. Many studies have suggested that natural forests can sequester much carbon to mitigate climate change but this varies from one forest type to another (Munishi *et al.*, 2004). In addition, closed natural forests have higher degree of biological diversity due to heterogeneity of their structure and composition (Merino *et al.,* 2007).

2.2.1 Forest structure

Forest structure is specifically defined as the species composition and its distribution, tree sizes on a forest area, diameter distribution and their spatial distribution. According to Mbwambo *et al.* (2008), forest structure characterized the number of parameters includes stocking, basal area, volume and their spatial distribution of species and tree sizes on a forest area. Stands with more complex structures and well defined distribution of species and tree sizes are thought to be more resilient and potentially even more productive (Husch *et al.,* 2002). They provide valuable habitats for greater diversity of plants and animals than do stands with less structural complexity Moreover, forest structure had physical form of stand, with particular emphasis of both living and dead plants occupy different layers from the ground to the top of the tallest trees.

2.2.2 Species composition

Species composition is the assemblage of plant species that characterize the vegetation (Martin, 1996). Understanding species composition is vital to helps determining forest condition and trend, which are precious tools to judge the impact of preceding management and guide future decisions (Mbwambo *et al.,* 2008). In order to determine forest structures, it was logical to conclude the forest carbon stock that provide knowledge of forest structure which is necessary for predicting possible losses and storage of carbon stock (Merino *et al.,* 2007).

It has been reported that tropical natural mixed forests are complex ecosystems characterised by high number of different species of different age and sizes (Maliondo *et* *al.*, 2000; Malimbwi and Mugasha, 2001; and Munishi and Shear, 2004). In order to determine forest stocking, species composition and diversity of these complex forest ecosystems, it is logical to express forest stocking by sizes for each species. This has been reported for many studies from different forest reserves and indicated different carbon storage potential of forests. For instance in Asia, Lasco *et al.* (2005) reported 13.2 $tCha^{-1}$ in a disturbed forest. In Tanzania, carbon stock in trees biomass including roots was 517 ± 17 $tCha^{-1}$ in Usambara and 388 ± 10 $tCha^{-1}$ in Uluguru Mountain Forest (Munishi and Shear, 2004).

2.2.3 Stand density or stocking

The number of stems per hectare shows the stocking level of trees in a specified forest area (Husch *et al.*, 1982). The stocking level (stems ha^{-1}) is linked to forest productivity or growth and yield potential. Proxies used include canopy closure, number of mature trees, number of preferred trees, density, cut stumps, growing stock, regeneration capacity, stand maturity, lopping, species composition, extent of grazing and soil surface erosion (Lambin *et al.*, 2003; Souza *et al.*, 2003). It is accepted that forest degradation is the reduction in number of stems per area, changes of carbon, species sizes, structure, and the capacity of a forest to produce timber (Panta *et al.*, 2008). Results from the previous inventory of 1997 in Zanzibar coral rag forest indicated that stems per hectare were 1594 (Leskinen *et al.*, 1997).

2.2.4 Basal area and volume

Stand basal area and volume are useful measures to compare the stocking of stand species, age and height. Species composition varies with time and is associated with seasonal rainfall fluctuations, unpredictable disturbance and environmental contrasts (Munishi, 2001; Mbwambo *et al.*, 2008). Tree size and conditions contribute to structural diversity, that is, large trees have high basal area and volume. The mean basal area and volume of KPFR in Zanzibar estimated during the 1997 biomass inventory were 4.51 m^2ha^{-1} and 35.73 m^3 ha^{-1} for coral rag forest respectively (Leskinen *et al.,* 1997). Other study reported basal area of 3.9 – 16.74.51 m^2ha^{-1} (Backeus *et al.*, 2006).

2.2.5 Species diversity

Species diversity is defined as the number of different species in a particular forest in relative frequencies while species richness is the actual number of different species in the forest (Harrison *et al.*, 2007). Species biodiversity index increases with the number of species in the community but in practice, biological communities does not exceed 5.0 (Kent and Coker, 1992). Species diversity is determined by Shannon & Winner Index and forests with low Shannon & Winner Index have low number of species. It was chosen because it combines species richness and evenness and is less affected by sample size compared to other indices (Kreb, 1989). It was reported that species diversity in the country differs from place to place (Giliba *et al*., 2011). Backeus *et al.* (2006) reported 86 tree species from Miombo woodland in Hombwe village, Mikumi Kilombero District, Tanzania.

2.2.6 Carbon storage in natural forests

Forests play a vital role in mitigating global warming, as the largest terrestrial store of carbon, after coal and oil, but the third-largest source of carbon emissions (Nabuurs *et al*., 2008**).** It can act and behave as a carbon source or sink as trees remove carbon dioxide from the atmosphere through photosynthesis and the same time act as ‘carbon sink’. Forest store carbon in their leaves, branches, stems, bark and roots depending on the balance between uptake of carbon through photosynthesis and release of carbon through respiration, decomposition, fires, or removal by harvest activities. The inventory of 1994 estimated that an emission per capita in Tanzania was 1.3 CO_2-e (GHGs) and 0.1 tCO_2 is the leading emitter of carbon due to deforestation and degradation (Yanda, 2010). Godoy *et al.* (2012) reported 0.2 Mt of CO_2yr^{-1} in 1997 -2007.

Zanzibar coral rag forests had average biomass of 26.39 tha^{-1} or equivalent to13.2 $tCha^{-1}$ (Leskinen *et al.*, 1997). IPCC (2003) reported that above ground carbon is the most practical carbon pool to monitor than below ground, litter, dead wood and soil organic carbon. However, forest degradation can significantly influence other carbon pools. FAO (2006) estimated above ground carbon in Asia of closed forest and open forests of undisturbed and disturbed forest were 98.2 and 46.6 and 39.5 and 13.2 $tCha^{-1}$, respectively. Field estimations of biomass and total carbon storage for specific forests ecosystems are essential since there is great disparity in carbon storage (Munishi, 2001; Munishi and Shear, 2004). The sum of carbon stored in a forest stand depends on its age and productivity and sizes of trees (Gurney, 2008). For instance, large size trees have large capacity for carbon storage than small ones, though young trees have higher rate of carbon sequestration than older ones (Mackey *et al.*, 2008). It is quoted by Brendan *et al.* (2008) that, '*to date, our thinking about conservation of forest ecology, forest conservation policy and climate change is confused, it is needed to re-consider forest in forest ecology and climate change context and take a fresh look at forest conservation'.*

2.3 Forest Degradation

There is no accepted global definition of forest degradation and is quite confusing, as most literature and experts do not give a clear-cut distinction between degradation and deforestation. International negotiations are currently debating on how to define "forest degradation" and erroneously focused on forest context. It is recognized that forest degradation means different things to different people, depending on their point of view or interest in forest and ways of measuring forest degradation had to be determined to reflect those differing points of view (FAO, 1997). In the context of climate change negotiations, it is fundamental that it should be defined in terms of loss of carbon stocks, even though there are other forest ecological and biophysical processes that can be degraded (FAO, 2007).

It has been reported by Di Gregorio and Jansen (2000) that degradation is characterized by fewer trees, lopped trees, unwanted species, heavy grazing pressure, unpalatable species and encroached forests which are characteristics considered as a degraded forest. Many of these definitions are expressed as challenges since there are no official statistics of degradation rate in respect of the forest parameter degraded which lead to uncertain emission reduction (Waston *et al.* 2013). In fact, estimating loss of forest biomass from deforestation and how much forest loss from creeping degradation is tricky because most countries do not monitor degradation at all (FAO, 2005). From hypothetical situations of different definition options, summary of multi - dimensions of forest degradation phenomenon (both broad set and narrowed definitions) as sought from various literature reviews was framed to illustrate the key features and implications. A summary of different definitions of forest degradation according to change in forest parameters are shown in Appendix 1. People are the main drivers of deforestation as they are almost wholly dependent on forests and therefore contribute largely towards the drivers of degradation. Brendan *et al*. (2008), quoted as saying that, *''It has been argued that a single major cause of degradation is that forest resources are grossly underpriced and are therefore undervalued by society that has lead to large forested areas being impoverished by degradation''*.

In Africa, deforestation increased dramatically from year 2000 to 2005 where net losses of about 3.64 million hectares annually were reported (FAO, 2010). The annual rate of degradation is almost 50 % of deforestation rate (Lambin *et al.*, 2003). Deforestation rate in Mozambique coastal forest was 1.4 % per year in 1991 – 1999 and 0.8 % per year from 1990 – 2004 (Jansen *et al.*, 2008). Thus, the global scientific community views that there is weak environmental policy and law on deforestation and forest degradation as the source of climate change, one of the most significant environmental problems of the 21 century and the problems of the next 100 years; endangering the sustainability of the world's environment health (UNEP, 2006). This is because, release of carbon through forest degradation as a result of forest fire, pest infestation are fast while sequestration of carbon through photosynthetic process is quite slow, taking ages (FAO 2006). Uncoordinated land use results into land use/cover change that accounts for 19 % of global carbon emissions and over a third of emissions from developing countries (UN-Habitat, 2004).

In Tanzania, forest degradation is widespread, both in reserved forests and on general land forests and the rate is estimated to be in order of 500 000 ha year^{-1} (URT, 2009). Tanzania is threatened by large scale deforestation in some areas as well as degradation in other. In Brazil, forest degradation accounted for 20 % of total greenhouse emissions (Asner *et al.*, 2005). Tanzania total forest area was destroyed at a rate of 1.16 % per year in period 2005-2010 and according to REDD, annual degradation rate was estimated to be in the scale of 500 000 hectares, while annual deforestation rate estimated at 412 000 hectare per year (FAO, 2007).

Coastal forests in Tanzania had 273 700 ha of forest in 2007 of which, deforestation rate of 1990 – 2007 duration was 3735 hayr^{-1} or 1.0% yr^{-1}. Also deforestation rate of 2000 – 2007 was 1223 hayr^{-1} or 0.4 % yr^{-1} (Fabiano *et al.*, 2011). Tanzania tropical dry forest habitats had biomass of 60 tCha^{-1} (FAO 2010). Another studies reported biomass of

157 $tCha^{-1}$ at low to medium level of degradation forest and at highly degraded Eastern lowland forest, the biomass recorded was 33 $tCha^{-1}$ (FBD, 2007). Further more, study done at degraded forest around Dar es Salaam about 200 km from the city reported biomass of 52 $tChayr^{-1}$ to as low as only 4 $tChayr^{-1}$ for most heavily degraded forest on the city margin (Aherends *et al.*, 2010). Consequence of deforestation and forest degradation is the increase of amount of carbon dioxide by more than 30 % since pre-industrial times and is currently increasing at an unprecedented rate of about 0.4 % per year globally, mainly due to the combustion of fossil fuels and deforestation (UNFCCC, 2008). They further reported that, since late nineteenth century, the mean global temperature has increased by 0.4-0.8°C and sea level has risen by 10 to 15cm. A doubling of the CO_2 concentration in the atmosphere is expected to cause an increase in the global mean temperature of 1.5 to 4.5°C.

2.4 Assessment of Natural Forest and Carbon Stock

Globally, over 130 nations conduct national greenhouse gas emission inventories through assessing deforestation and forest degradation (Brown *et al.*, 1994). Forest inventory is defined as the procedure of obtaining information on quantity and quality of the woodland resources and other characteristics of the land on which trees and shrubs are growing (Malimbwi, 1997). Previous analyses have suggested that carbon stock varies between forests reserves, size of forest area, tree size, diameter distribution and type of species (Mbwambo *et al.,* 2008). This necessitates field measurement for assessing forest biomass and further total carbon storage for specific forest ecosystems (Munishi, 2001; Munishi and Shear, 2004).

Forest biomass, expressed in terms of dry matter weight of living organisms is an important measure for analyzing ecosystem productivity and also for assessing energy potential and the role in the carbon contents. Assessing degradation of forest structure is the most practical way to monitor average carbon stock per unit area (IPCC, 2003). Quantifying biomass density, emissions and removal for tropical forests (Angelson *et al.*, 2010) was initially made by the FAO (2003) based on computerized data base. Forest stand parameters like diameter at breast height were used to compute tree volume that could be used to compute biomass and then converted into forest carbon (Husch *et al.*, 2002). It is accepted that forest degradation is the reduction in number of stems per area, basal area, volume and carbon (Panta *at al.*, 2008). Proxies used the followings as symptoms of forest degradation, these include; canopy closure, number of mature trees, number of preferred trees, density, cut stumps, growing stock, regeneration capacity, stand maturity, tree lopping, decrease species composition, grazing and soil surface erosion (Lambin, 1999; Souza *et al.*, 2003).

2.5 Role of REDD to Improve Forest Management

The United Nation led ongoing agenda on forest management in negotiations under the UN Framework Convention on Climate Change (UNFCCC), proposed Reduced Emission from Deforestation and Forest Degradation (REDD), aimed at curbing deforestation (Angelsen *et al.*, 2009). Given the significance of degradation, UNFCCC requires that the "degradation" component of REDD must explicitly be dealt with and failure to do so will reduce the effectiveness of the mechanism in mitigating climate change. REDD programmes envisage making carbon trade direct monetary payments to encourage developing countries to upgrade forest resources and to roll back deforestation. Incentives will be performance-based payments in carbon trade, and will entail a reform in forest policies and institutional management to conserve forests.

Incorporating degradation into a REDD framework, is also critical for channeling incentives to the diverse range of stakeholders involved in the spectrum of activities that determine the fate of forests and their carbon emissions. It entails providing information on realized changes in forest carbon stock to qualify for funds from international sources and an effective institution to manage information and incentives (Wunder, 2008). REDD appears at international level to counteract existing processes of deforestation, so there is a need to formulate wider ecological effectiveness information (Barret *et al.,* 2001).

2.6 Evolution of Forest Management in Zanzibar

Historically, colonial authority in Africa, exerted power on protected areas using the "fence and fine" approach and became a norm that was inherited by national governments during independence (Mackey *et al*., 2008). The forests of Zanzibar are globally acknowledged by Conservation International is one of the 200 global biodiversity hot spots (DCCFF, 2003). It is managed in effort toward implementing the Agenda 21 of Rio Summit of 1992. Forest management effort in Zanzibar were supported by international organizations like FiNNIDA in the 1980's to 1990's, CARE International Tanzania in 1995 to 2004 and Wildlife Conservation Society (WCS) in 1984.

Historically, Zanzibar forest was recognized by the colonial government since 1940's with the introduction of Wood Cutting Decree in 1947 and Forest Reserve Decree of 1950. Currently, Zanzibar is exercising Community-Based Natural Resource Management (CBNRM) with emphasizing on involving local people through empowerment and collaborative agreements (Kombo, 2003). Joint Forest Management (JFM) has been commonly used in Tanzania (Kajembe *et al.*, 2004). Successful examples of JFM in Tanzania are found in Kitulangh'alo Forest Reserve, Amani Nature Reserve, Kwizu and Nkweshoo Forest Reserves (Kajembe *et al.*, 2004). The establishments of the first National Park in Zanzibar, Jozani National Park (Jambiya *et al.*, 2004) and creation of Ngezi Nature Reserve, are well known success stories of Participatory Natural Resource Manament (PNRM) in Africa, that have ensured safe and sustainable resource protection in Zanzibar.

CHAPTER THREE

3.0 MATERIAL AND METHODS

This chapter deals with description of the study area, method of data collection and analysis. Inventory was used to collect data of forest structure and carbon stock at Kiwengwa Pongwe Forest Reserve, Zanzibar.

3.1 Description of the Study Area

3.1.1 Location

KPFR is located on North-eastern side of Unguja Island approximately 45 km from Zanzibar town (Fig. 1). Geographically, Zanzibar comprises two sister islands of Unguja and Pemba Island located between latitude 4˚ and 6˚ south of the Equator and between 39˚ and 40˚ East of the Greenwich. The islands lie about 35 km in the Indian Ocean off the east coast of the mainland Tanzania, with which they form the United Republic of Tanzania. This study was conducted in KPFR at *Kaskazini* (North) Region of Unguja Island which is north of Zanzibar Municipality.

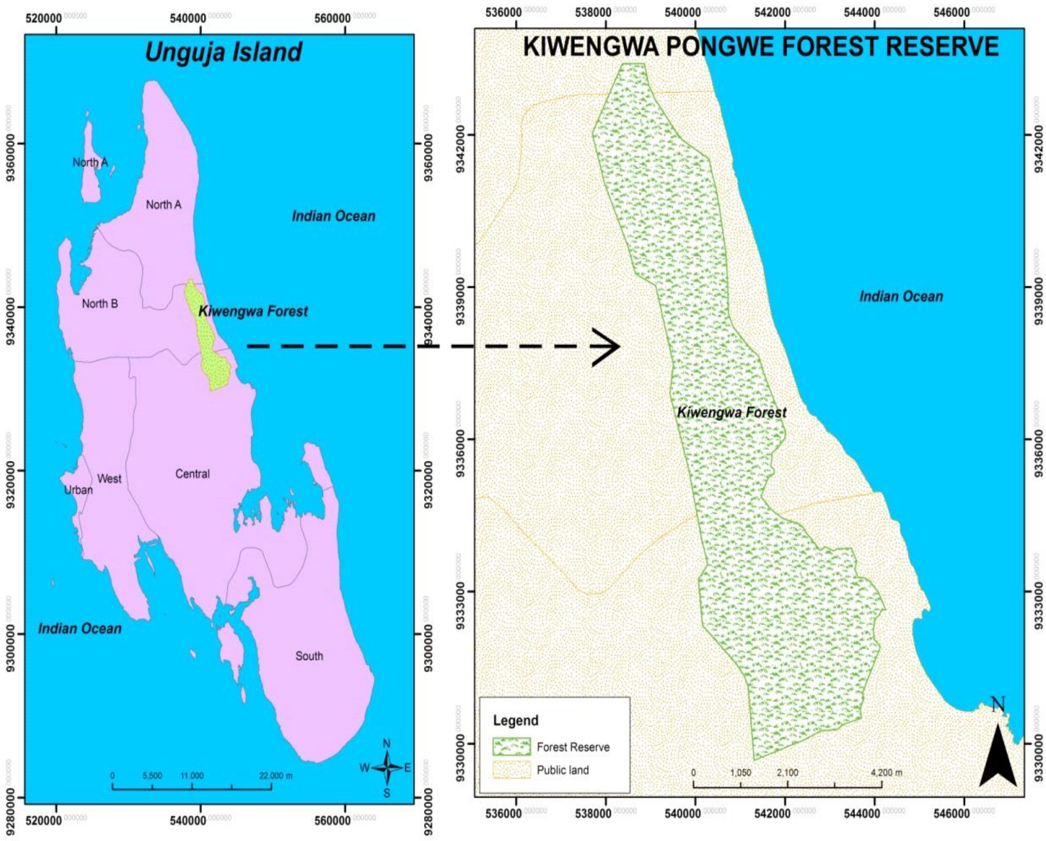

Figure 1: Map shows location of study area

Source: DCCFF (2007)

3.1.2 Topography and climate

The forest reserve is located at the foot of Mchekeni rim, which is considered to be the highest point, about 40 meters above the mean sea level. Long stretches of coral reefs are found on the western side parallel to the reserve and range between 15 m and 40 m tall. The study area enjoys Zanzibar’s climate, which is characterized by bimodal pattern of rainfall with an average annual rainfall of about 1750 mm with long rains falling from March to May and the short rains from October to December. Annual temperature range between 18 ˚C–34 ˚C, of which the maximum annual average temperature is 32 ˚C which recorded from January to March and the minimum annual average temperature is 22.3 ˚C that is recorded from June to August. The reserve is located between 0 – 120 m above sea level and experiences high humidity, which varies from as high as 87 % to low of 76 %. The study area is characterized by coral rag soils that support the only evergreen natural forest in the Northern zone of Unguja Island.

3.1.3 Vegetation and other ecological values

KPFR has more than 69 plant species in a mosaic of vegetation types with highest canopy of about 20 meters tall that encompass scrub forest, medium to high coral rag, grassland, bracken-fern regenerating areas and a forest high coral rag rim extending along the western border of the reserve. Some species are threatened to extinction, and some are of local and global significance. The forest that encompasses scrub forest on the medium to high coral rag; and grassland and bracken-fern regenerating areas is part of the Coastal Forests of East Africa (Silima *et al.*, 1993).

Being the second largest area of continuous high coral rag forest in Zanzibar, the high forest under storey of KPFR is cycad-dominated. Common canopy emergents are *Terminalia boivinii, Mystroxylon aethiopicum, Diospyros consolatae, Ozoroa obovatta, Ficus natalensis* and *Mimusops frutcosa.* Threatened plant species are *Aleuritus molucana* (mkaa), *Vernonia zanzibarica* (mtumbaku mwitu), *Olea woodiana* (kidaramba), *Carpodiptera africana* (muwanga) and *Pittosporum viridiflorum* (mpande). Other species having local and global significance in Kiwengwa-Pongwe Forest Reserve are: *Allophylus parvilei, Stadmania pereskiifolia* (only found in a confined narrow belt with few individual species that have not been seen elsewhere in Zanzibar forests), *Drypetes natalennis, Teclea simplicifolia, Rawsonia lucida, Teclea nobilis, Sorindeia madagascariensis and Blighia unijugata* are quite common throughout the forest. In addition, the forest harbors *Zanthoxylum holtzianum, Croton sylvaticus and Capparis species* which are widely used as medicinal plants (Kombo, 2003).

The reserve is very rich in biodiversity of national and international importance. In terms of flora, KPFR is a home of many plant species, which have medicinal as well as aesthetic values. The scenic value of this reserve is evidenced by the number of landscape features available including historic caves which have not yet been fully exploited as tourism opportunities for local communities. Integrated cultural activities are conducted in these caves that append high social value to the reserve.

3.2 Data Collection

3.2.1 Reconnaissance survey

Field reconnaissance survey was conducted for two days before data collection. This focused mainly on the familiarization of the study area and all preliminary activities such as the establishment of the number of plots. The reconnaissance survey helped to come out with best tactics of conducting reseach thus easing the distribution of sample plots all over the study area. The number of plots were calculated as follows:

Number plots (n) = $N= t\ ^{2}CV^{2}/SE^{2}$ (Phillip, 1994) ………………..…………………. [1]

t= 1.6449, SE=0.1(sampling error should not exceed 0.1),

sd=6.6, mean=13.8, CV(x/sd)=0.57

Number of plots = (1.6449*0.57/0.1)^2= 88

Where

N = Number of plots

t = Critical value

CV = Coefficient Variation

Sd = Standard Error

X = Mean

3.2.2 Sampling design

A combination of random and systematic sampling techniques was adopted. The first plot was randomly selected whereas the others were systematically aligned. The distance between transects was 600m and between plots was 300 meters. A cluster of concentric circular plots of radius 2, 5, 10 and 15 m were established to capture different forest stand parameters. Circular shaped sample plots were adopted instead of square and rectangular plots because they are easy to use, reduce edge effects in the samples and minimize counting errors during inventory of borders (Krebs, 1989). Moreover, circular plots increase measurement accuracy and accuracy of sampling intensity of large areas and save time.

Nested plots ensure that all measurements of small and large size trees were taken in small and large plots, respectively. The plots were established with the aid of a compass and a 50m tape measure. Upon reaching a sample plot, a centre was temporarily marked using wooden peg, and with coloured ribbons tied at each boundary of respective circle radius so as to facilitate the location of different radii on the ground. Thereafter, GPS coordinates were recorded at the plot centre

3.2.3 Data collection on forest structure for standing and removed trees

Trees parameters to be collected in the field for the purpose of determining forest structure include diameter at breast height for standing trees (DHH), species identification and stump diameter for removed trees. These will be used to derive information on composition, stand density, basal area, volume and carbon stock. Field data collected in each plot were obtained follows; at 2 m radius all trees were counted, at 5 m radius all trees of diameter at breast height (DBH) >5cm but <10cm were measured. In the 10 m radius all trees with diameter > 10 but <20 cm were measured and at 20 m radius all trees with diameter >20 cm were measured.

3.3 Data Analysis

The variable for each standing and removed trees (stump) was separated by group of diameter classes and each class were computed based on convenient size class. Data analyses were arranged by order of transect number, plot number, species code and species name. Checklist of all species were arranged by order of local names and matched with botanical name and family. Sample trees for development of height diameter equation were measured before actual analysis. The computation was as follows:

3.3.1 Forest structure for standing trees

From the collected data, the following parameters were computed by using formulae and equations described as follows;

a) Species composition of KPFR

Species composition was determined as the list of all trees encounterd by defining their names and family. The most common measure of composition is richness (the number of different species), abundance (the number of individuals per species found in specified area) and dominance (basal area of different species). The Importance Value Index (IVI) was used to describe species composition as shown below;

IVI = sum of (RF+RD+RBA)/3..[2]

Where;

RD = Relative Density, RF = Relative Frequence and RBC= Relative Basal Area

RD = (Number of individuals of a species)/(Total number of individuals of all species) x 100

RF = (Frequency of one species)/(Sum of all frequencies) x 100

RBA = (Combined Basal area of single species)/(Total Basal area of all species)x100

IVI was used because it entails the following;

1. How commonly species occurs across the entire forest.
2. The total number of individuals of the species
3. The total amount of the forest area occupied by the species

b**) Stand density**

The number of tree counted in each plot was expressed as trees per hectare basis using the following formulae:

$$N = \frac{1}{m}\sum \frac{ni}{ai} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{[3]}$$

Where;

N = Number of stem per ha

m = Number of plots

ni = Number of trees per plot

ai = Plot area

c) Basal area and volume per hectare

The basal area of all trees in each plot was summed and divided by the size of the plot as indicated as follows;

$$G = \Sigma Gi/n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{[4]}$$

Where;

G = average basal area per ha of the stand (m^2ha^{-1});

Gi = basal area of the i*th* plot ($m^2/ha\text{-}^{-1}$i*th*) and

n = number of sample plots (Malimbwi, 1997).

Volume was obtained by using the equation by Malimbwi *et al* (2005) which converts diametet at breast height to volume as shown in Equation 5.

$V = 0.000011972D^{3.191672}$ ……………………………..……………………….. [5]

Where;

V = tree volume (m^3) and

D = tree dbh (cm)

($R^2 = 0.98$)

d) Biodiversity indices

Species diversity was used to asses forest structure (Pomerining, 2000). Shanon & Wiener Diversity Indices used to determine the biodervisity of KPFR and was selected because it combines species richness and evenness and is less affected by sample size compared to other indices (Krebs, 1989). Shannon & Wiener Index were computed as shown in Equation 6;

$H = -\sum (Pi \ln Pi)$ ………………………………………………………….. [6]

Where;

$\sum$ = Summation symbol from of Pi^{th} to i^{th} species

$Pi = ni/N$

ni = total number of individuals in the ith species

N = total number of individual of all species

Ln = Natural logarithm

e) Biomass and carbon stock for KPFR

Equation used in this study was developed at similar geographical location and same vegetation type of coral rag tree species during wood biomass inventory took place in Zanzibar as developed by Leskinen *et al.* (1997). Tree biomass derived from this equation was computed as a product of total tree volume and wood basic density. The equation had $R^2 = 0.97$.

The equation used was;

$$Biomass = \exp\left(-2.60611\right)^{*} d^{2.50797} \quad \text{……………..……………..} \ [7]$$

f) Carbon

Tree biomass obtained in Equation 8 was converted to carbon as shown in equation below:

Carbon = Biomass x 0.49 (kg) (Brown, 1997)………………………………… [8]

g) Carbon dioxide emission

Carbon dioxide stored or emitted was computed by the multiplication of carbon obtained in equation 8 by carbon dioxide equivalent (CO_2-e) as shown in Equation 9

CO_2 (emitted/stored) = Carbon x CO_2-e = 3.67……....………………………… [9]

3.3.2 Forest structure and carbon stock for removed trees

The stand structure for removed trees was done the same way as standing trees. The only exception was after stump diameter (SD) was computed; diameter at breast height was computed by using the following equation;

DBH = 0.9684 x SD – 0.6278, (Munishi and Shear, 2004)….…….……….. [10]

Where;

DBH = Diameter at Breast Height (cm), and SD = Stump diameter (cm)

CHAPTER FOUR

4.0 RESULTS AND DISCUSION

Results of the forest structure and the effect of forest degradation on forest structure and carbon stock in KPFR are presented and discussed in this chapter.

4.1 Forest Structure and Carbon Stock

4.1.1 Species composition

A total of 60 different trees species were identified belonging to 52 families in KPFR. The Importance Value Index (IVI) showed that *Mystroxylon aethiopicum* was the most dominant species (17.3 %), followed by *Terminalia boivinii* (10.4 %) and *Allophylus pervillei* and *Sterculia africana* were the least important species in the forest with a value of 0.08 % and 0.09 % respectively (Table 1; Appendix 7).

Table 1: Tree Species Composition and Structure in KPFR

Species name	BA($m^2ha^{-1)}$	Density/ha	RBA	RF	RD	IVI%
Mystroxylon aethiopicum	51.64	74.95	0.20	0.16	0.16	17.3
Terminalia boivinii	32.07	30.98	0.12	0.09	0.09	10.4
Diospyros consolatae	18.55	43	0.07	0.07	0.07	7.2
Olea woodiana	31.68	34.8	0.12	0.05	0.05	7.1
Ozoroa obovatta	21.70	23.04	0.08	0.04	0.04	5.5
Mimusops obtusifolia	11.97	21.56	0.05	0.05	0.05	5.0
Macphersonia gracilis	8.29	25.38	0.03	0.06	0.06	5.1
Eugenia capensis	4.96	22	0.02	0.06	0.06	4.6
Euclea natalensis	3.08	21	0.01	0.06	0.06	4.2

A previous study of the same forest by Leskinen *et al.* (1997) reported 69 trees species, slightly higher than 60 reported in this study. The close similarity in species richness in this study to the previous one may be due to low disturbance of the forest which is now reserved. However, this value of species richness is lower than that reported elsewhere in coastal forests of Tanzania. For instance, Swai *et al.* (2011) reported 75 species at Mlole Forest Reserve in a coastal forest area in Mafia, Tanzania.

Mystroxylon aethiopicum was the dominant species in KPFR plant community indicating that it is an important element in the forest. The species is among the most common in coral rag forest species and regenerates vigorously in coral forest communities (Leskinen *et al.* 1997). In a previous study, *Euclea racemosa* was the dominant coral rag species in the forest followed by *Polysphaeria parvifolia* (Lisknen *et al.*, 1997). This difference could be due to the level of disturbance of individual species. The variation in species dominance and richness can be linked to the level of disturbance, quick species recovery after harvesting, regenerative potential and effective sprouting from stumps reported by Poyry (1983). However, species richness differs from one forest to another depending on the function of the area and its heterogeneity. This could be attributed to the fact that the forest is now a protected forest reserve contributing to greater chance of many species to grow (Munishi and Shear, 2004).

4.1.2 Stand density/stocking, basal area and volume

Total number of stems per hectare was 845 stems ha^{-1} with an inverted ‘J’ shape distribution pattern with sharp drop of stem density with increasing diameter (Table 2). This indicates that most of stems were in a diameter class 4.5-10 cm (705 stems ha^{-1}) followed by 10.5-20 cm (116 stems ha^{-1}) and fewer trees were in diameter class > 20 cm (24 stems ha^{-1}).

Table 2: Stocking, Basal area and Volume by Diameter Class of Trees Sampled in KPFR

Diameter class (cm)	Stocking (Stems ha^{-1})	Basal area (m^{2}ha^{-1})	Volume (m^{3}ha^{-1})
4.5-10	705	1.2	8.2
10.5-20	116	1.8	11
Above 20	24	2.75	14.6
Total	845	5.75	33.8

Inverted J-shape distribution pattern might indicate that stands are recovering through natural regeneration (Isango, 2007). Alternatively, the inverted ‘J’ shape could indicate forest degradation where the big trees are removed for different uses such as timber, poles and charcoal, leaving behind a forest dominated by smaller trees (Panta and Joshi, 2008). Stocking in this study was much lower than 1594 stems per ha^{-1} reported in the previous study done in the same forest in 1997 (Leskinen *et al.,* 1997). This could be due to over cutting of trees by adjacent communities who demand forest resources for their livelihoods (Makame, 2006). Generally, compared to other studies done elsewhere in coastal lowland forests of Tanzania, stem density reported in this forest was relatively low. For instance, Leskinen *et al.* (1997) recorded 1022 and 663 stems ha^{-1} in Jozani Forest and Ngezi Forest Reserve respectively in Zanzibar.

Basal area and volume distribution by diameter classes were lowest in small diameter trees (4.5-10 cm) with 1.2 m^2ha^{-1} and 8.2 m^3ha^{-1}, respectively (Table 2). Total basal area and volume were 5.75 m^2ha^{-1} and 33.8 m^3ha^{-1}, respectively (Table 2). The basal area in this study was higher than 4.51 m^2 ha^{-1} reported in the study done at the same forest in 1997 (Leskinen *et al.*, 1997). This could be due to the fact that KPFR is currently being reserved unlike 1997 when the forest was not reserved. The increased basal area can also be due to increasing trees size over time. Compared to other studies done elsewhere in coastal forests, the basal area in this forest is however much lower. For instance, Ahrends (2005) reported overall standing basal area of 21.9 m^2 ha^{-1} in lowland coastal forests in Coast Region, Tanzania. By contrast, the volume in this study was slightly lower than 35.37 m^3ha^{-1} reported earlier for KPFR (Leskinen *et al.,* 1997). The decline in mean volume was linked to forest degradation where big trees were being removed for different uses (Leskinen *et al.,* 1997). Charcoal and lime making activities were the most likely cause of KPFR degradation due to ever increasing energy demand by most people in Zanzibar (Makame, 2006).

4.1.3 Species diversity

The average Shanon & Wiener Index of diversity was 1.34 (Table 3: Appendix 8) suggesting medium species diversity in KPFR. Table 3 further shows that variation of species diversity increased from the forest margin to the centre of the forest.

Table 3: Variation of Species Diversity with distance from edge to forest centre in KPFR

Number of Plots	Distance (m)	Shannon Index
26	50	0.83± 12
25	300	1.24±18
21	600	1.32±17
13	900	1.55±11
3	1200	1.74±38
	Mean	**1.34±17**

The variation in species diversity within the forest was attributed to fact that many edge plots had few trees. Species diversity increased significantly (p<0.01) from the forest edge to the forest centre (Table 4).

Table 4: Regression Analysis on Variation of Indices of Edge and Centre Forest in KPFR

	df	SS	MS	F	P. Value
Regression	1	342.42	342.47	35.69	0.009**
Residual	3	28.77	9.59	-	-
Total	4	371	352.06		

** denotes statistical significance difference (P < 0.01)

Increased species diversity from the edge to centre of the forest could be due to factors such as human disturbance in the forest and management approach. Species noted to have high contibution acros the forest include *Mystroxylon aethiopicum* (0.29), *Olea woodlana*

(0.22), *Terminalia boivinii* (0.21), *Eugenia capensis*, *Diospyros consolatae* (0.19), (0.16), *Encephalatos hilderbrandtii* (0.15), *Mytenos mossambiceansis* (0.5), *Mimusops obtusifolis* (0.14), *Ficus ingens* (10.14). *Polyshaeria parvifolia* (0.13) and *Macphersonia gracillis* (0.12). (Appendix 9).

Normally, Shanon & Wiener Index range from scales (1-5) with 1 indicating poor diversity and 5 indicating high diversity; the larger the index the higher the species diversity in a given community. The value of species diversity in this study is consistent with that reported for other coastal forest in Tanzania. Madoffe *et al.* (2012) reported Shannon Index of 1.68, 1.58 and 1.24 of Gumba Village Forest Reserve, Kivahili Central Government Forest Reserve and Local Government Forest Reserve respectively, in Handeni District. However, Swai *et al.* (2011) reported species diversity index of 3.5 and 2.5 of Mlole Forest Reserve and Juani Forest Reserve in a coastal forest area in Mafia, Tanzania. This was linked to high level of human disturbance in KPFR for fire wood, building material and charcoal making.

4.1.4 Biomass

The biomass of standing trees was 22.9 tha^{-1} in KPFR. The distribution of biomass by dbh class revealed higher biomass in dbh class > 20 cm (10.4 tha^{-1}) compared to other dbh classes. This was because the larger trees have higher biomass. This biomass is slightly lower than 26.39 tha^{-1} earlier reported in the same forest by Leskinen *et al.* (1997) which could be due to the fact that, the biomass reported in 1997 included also trees with dbh ≥ 2 cm and above, while in this study considered only trees with dbh ≥5 cm.

Similarly, the biomass reported in this study was much higher than that reported from other forests in Zanzibar. For example, Leskinen *et al.* (1997) reported 7.91 tha^{-1} and 12.76 tha^{-1} biomass in coral rag forests that were close to the road and settlements and biomass that were far from the road and settlements, respectively. This was due to the fact that the forest was in public land with no control of the forest resources. However, compared to previous studies of other coastal forests in Tanzania, the observed biomass in this forest was much lower than 161.15 tha^{-1} and 165.08 tha^{-1} reported in Jozani Forest Reserve and in Ngezi Government Forest Reserve, Zanzibar (Leskinen *et al.*, 1997). Moreover, previous analyses have suggested that biomass varies between forests reserves, size of forest area, tree size, diameter distribution and type of species (Mbwambo *et al.*, 2008).

4.1.5 Carbon stock

Total carbon stock for standing trees at KPFR was 11.5 tha^{-1}. Carbon stock in dbh class 4.5-10 cm and 10.5-20 cm were similar (Figure 2). The trend suggests that carbon stock is increasing slowly with the increase in trees diameter, perhaps reflecting continued removal of trees in 10.5- 20 cm diameter class.

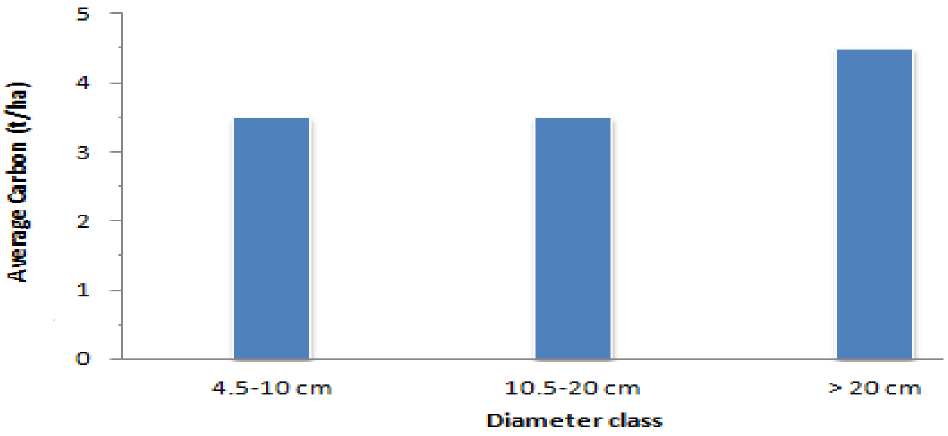

Figure 2: Above Ground Carbon by Diameter Classes in KPFR.

Trees with diameter > 20 cm had highest carbon stock (6.5 $tCha^{-1}$). The higher carbon stock may be associated with the size trees, with trees having higher capacity for carbon storage than smaller trees. The low total standing carbons of 13.5 $tCha^{-1}$ was linked to prevalence of small diameter trees throughout the forest. Gurney (2008) explained that the amount of carbon stored in a forest depends on size of trees. However, removal of trees in KPFR was associated with species preference by users and not determined by diameter classes.

The carbon stock in this study is lower than 15 $tCha^{-1}$ reported earlier for the same forest (Leskinen *et al.,* 1997) that can be associated with forest degradation. However, both in this study and the previous study (Leskinen *et al.,* 1997), the carbon stock is much lower than in most other forests in Tanzania. For example, FBD (2007) reported 157 $tCha^{-1}$ in Eastern lowland forest with low to medium level of degradation, and 33 $tCha^{-1}$ for a heavily degraded forest. Baccini *et al*. (2008) reported mean carbon stock of 57 ± 15.89 $tCha^{-1}$ for a forest located 220 km from Dar es Salaam and Ahrends *et al*. (2010) reported an average of 52 ± 4.99 $tCha^{-1}$. Also, FAO (2010) reported an average of 60 $tCha^{-1}$ in coastal forests of Tanzania. Poor forest structure and carbon stock in this study may be attributed to forest degradation through illegal tree cutting for fire wood and charcoal making (Kitwana, 2006). As reported previously, the average size of coral rag forests in Zanzibar are overwhelmed by small sized trees and hence the forest is expected to contain low carbon stock (Leskinen *et al.,* 1997).

Distribution of carbon stock by species revealed that trees species had different carbon storage potentials as expected for a natural forest. *Mystroxylon aethiopicum* had carbon storage of 2 $tCha^{-1}$, contributing more carbon than any other species in KPFR, followed by *Uvariodendron kirkii* (1.8 $tCha^{-1}$) and the lowest by *Salacia elegans* (0.003 $tCha^{-1}$)

(Fig. 3; Appendix 4). The high carbon storage by *Mystroxylon aethiopicum* is possibly due to its lower preference by users and large sized trees of the species.

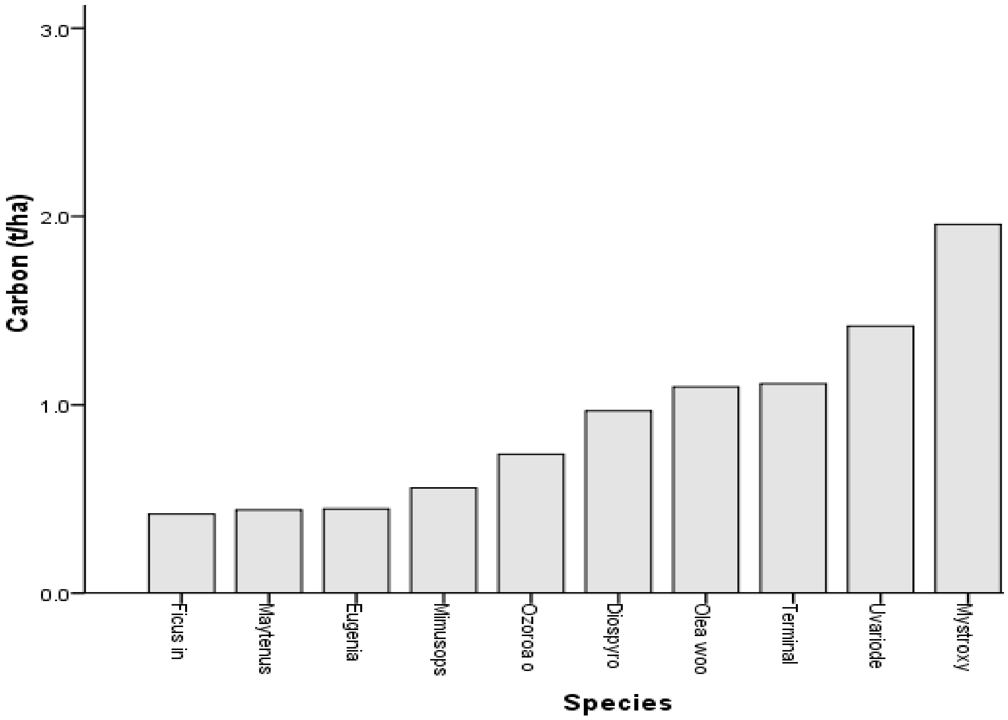

Figure 3: Carbon Stock by Species in KPFR

Both *Mystroxylon aethiopicum* and *Uvariodendron kirkii* (Fig. 3) contributed more carbon stock in the area because they were the most abundant species in the area. They regenerate well and are less disturbed because they are not attractive for extraction by local people (Kombo *et al.*, 2004). *Mystroxylon aethiopicum* for example does not burn well and generates too much smoke and hence is unattractive for charcoal production. Also, the two species have low mechanical properties making them unsuitable as construction materials. On the other hand, *Uvariodendron kirkii* is believed to be a medicinal species used by local people and so the tree is protected. *Salacia elegans* had the least carbon storage because the species is amongst the rare tree species and has very slow growth rate. This could also be explained by its over use as it is suitable for handles, poles and fuel wood (DCCF, 2003).

4.2 Effects of Forest Degradation on Forest Structure and Carbon Stock

The effect of forest degradation on forest structure and carbon stock in KPFR are presented in this section that include number of stems cut, basal area, volume, biomass and carbon stock removed.

4.2.1 Stand density/stocking (N) removed

The number of stems per hectare removed revealed an inverted J shape diameter class distribution (Fig. 4). Figure 4 indicates more trees were removed from diameter class 4.5-10 cm (366 stem ha^{-1}) followed by 10.5-20 cm (59 stem ha^{-1}) and the lowest was in the dbh class > 20 cm (10 stem ha^{-1}).

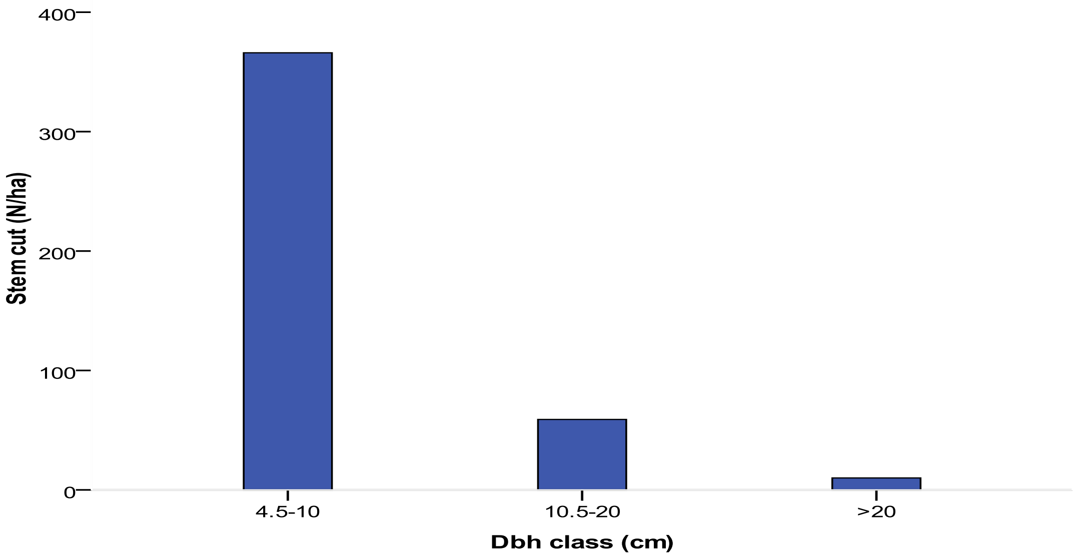

Figure 4: Number of Stems Cut (stumps) per hectare in Diameter Classes in KPFR

Higher removal of small sized trees could be due to the fact that forest is growing under high disturbance although it now seems to be improving with more recruitments as it is protected. Moreover, the main reason for high removal of small trees is that people cut small trees for different preferential uses, most commonly for building materials such as poles and withies for house building, hoe handles and fuel wood (Makame, 2006). The effect of removals in the forest structure is demonstrated in Table 5.

Table 5: Removed Forest Structure Parameters by Diameter Class in KPFR

Diameter class (cm)	Density (N/stems ha^{-1})	Basal Area (m^2ha^{-1})	Volume (m^3ha^{-1})	Biomass tha^{-1}	Carbon stock $tCha^{-1}$
4.5-10	366(84)	1.7(65)	3.2(18)	2.8(25)	1.6(26)
10.5-20	59(14)	0.7(23)	6.5(37)	4.3(39)	2.4(39)
> 20	10(7)	0.5(19)	7.9(45)	3.9(35)	2.1(34)
Total	435	2.6	18.0	11.07	6.11
% Removal	51.5	31.0	34.7	32.6	31.2

*** % removal as computed from total standing and removal

Various studies have indicated that cutting of forest resources is to address poverty problems. For example, Monela *et al.* (2007) reported that in developing countries, extensive tree harvesting associated with poverty conditions and high population pressure. In KPFR, trees harvested for charcoal and making lime to curb poverty (Plate 1).

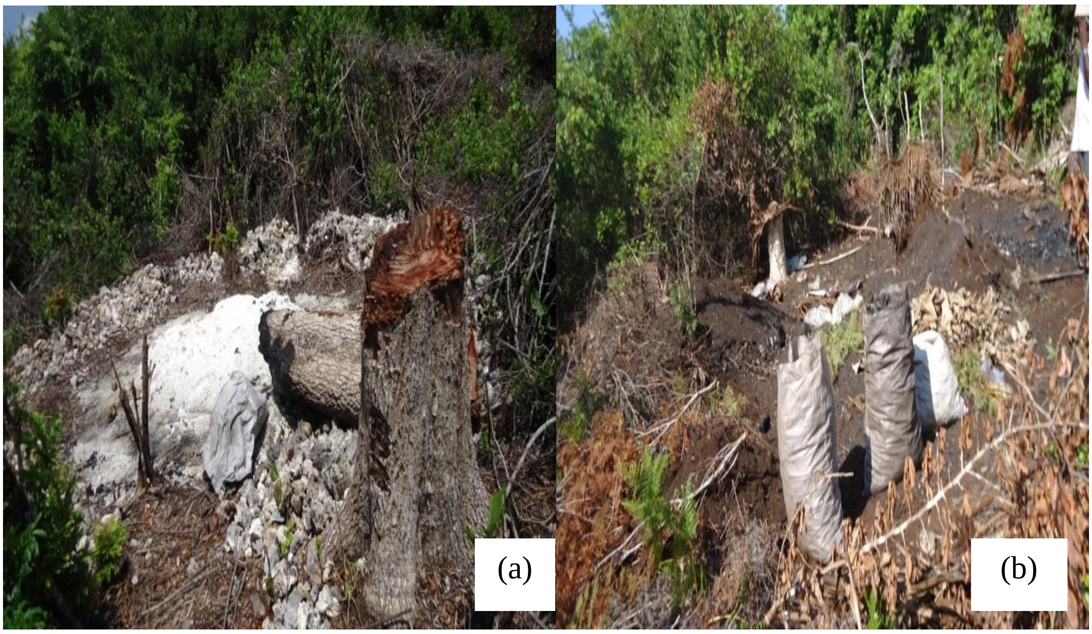

Plate 1: Tree Cutting for Charcoal and Lime making in KPFR

4.2.2 Basal area and volume removed

The total basal area and volume removed were 2.6 m^2ha^{-1} and 18 m^3ha^{-1}, respectively. Table 5 shows that the basal area and volume removal were 31 and 35 % of the pre-cut stand.The higher removal of basal area in lower dbh class (65 %) suggests that the forest is growing under high disturbance of regeneration and recruitment. The percentage removal of this forest signifies over exploitation of forest resources through fuel wood and building materials. In contrast, volume removal of 45 % was higher in the large diameter trees (> 20 cm) suggesting over cutting in this dbh class. Big trees are targeted for charcoal and lime making activities which was the most likely cause of KPFR degradation due to ever increasing demand for wood energy for most people in Zanzibar (Makame, 2006).

4.2.3 Biomass removal

Biomass removal as measured from stumps cut was 11.07 tha^{-1} (Table 5) representing removal of 32.6 % of the pre-cut stand. More biomass (74 %) was removed from smaller trees (>10<20 cm than from larger trees (> 20 cm). The higher removal of biomass in smaller trees suggested that the forest is growing under high disturbance of forest resources through fuel wood and building materials targeted for construction of wooden houses which are popular in the communities surrounding KPFR.

4.2.4 Carbon stock removal

The total carbon stock removed was 6.11 $tCha^{-1}$ representing 31.2 % as computed from total standing and removed trees (Table 5), indicating the extent of forest degradation in the KPFR. Carbon removal by diameter classes showed that more carbon stock was removed from trees with dbh class between 10 and 20 cm. This indicates that concentration of disturbance in this diameter class was high perhaps due to over utilization.

The tree species which lost more carbon were *Terminalia boivinii* (10.5 %), *Diospyros consulatae* (10.3 %), *Mimusops obtusifolia* (9.7 %) and *Mystroxylon aethiopicum* (9.1 %). They contributed 40 % of the carbon stock lost from the forest (Table 6: Appendix 5). These species were cut most because they are useful for building materials and hoe handles. Cutting of tree species was associated with specific species of preference for different human use. Some direct threats included charcoal production, logging for timber, grazing and expansion of agricultural land and some of the forest uses are non sustainable, causing threats to these forests. Lack of alternative sources of materials to meet their needs was the mojor root cause behind many of these pressures (Makame, 2006). For instance, species with good quantity of charcoal and market attraction for human consumption were heavily cut and thus lost more carbon stock (Leskinen *et al.*, 1997).

Table 6: Carbon Stock Removed by Species in KPFR

Species	Carbon stock removed ($tCha^{-1}$)	% removal
Terminalia boivinii	0.64	10.5
Diospyros consolatae	0.63	10.3
Mimosops obtusifolia	0.60	9.7
Mystroxylon aethiopicum	0.56	9.1
Milletia usaramensis	0.40	6.5
Ozoroa obovatta	0.38	6.3
Macphersonia gracilis	0.36	5.9

Number of standing removed in each diameter class (Table 7) were almost half of standing stock implies cutting were done in all diameter classes probably because of species preference in use and hence more degradation.

Table 7: Comparison of Number of Standing and Removed Trees in Diameter Classes in KPFR

Status	Diameter class (cm)			
	4.5-10	10.5-20	> 20	Total
Standing	705	116	24	845
Removal	366	59	10	435
Total	1071	149	40	1280
% removal	34	40	25	51.5

Analysis of variance of standing against removed trees (trees conditions) in KPFR showed that the amount of carbon in standing trees was significantly higher ($P< 0.01$) than the carbon in removed trees (Table 8). This could be linked with that KPFR has been gazetted since 2004 and thus conservation contributes to Green House Gas emission mitigation.

Table 8: Analysis of Variance on the Effect of Standing against Removed Trees on Carbon Stock in KPFR

Source of Variation	Sum of Squares	df	Mean Square	F	P.value
Tree condition	1575.462	1	1575.462	17.751	.000**
Error	53252.560	600	88.754	-	-
Total	54828.022	601			

** denotes statistical significance difference ($P < 0.01$)

Compared to other forests in the world, generally forest degradation is widespread in both forest reserves and general land forests in Tanzania (URT, 2008). In Africa, the annual rate of degradation is almost 50% of deforestation rate (Lambin *et al.,* 2003). Forest degradation in KPFR was further due to informal settlements, shifting cultivation and stone excavation for traditional houses (Plate 2a and b) which had implication on stocking and hence carbon stocks (Mertz, 2009). Other causes of forest degradation in KPFR included road construction, illegal timber harvesting and forest encroachment. ITTO *et al.* (2002) reported that forest degradation reduced crown cover, biodiversity, forest health and productivity.

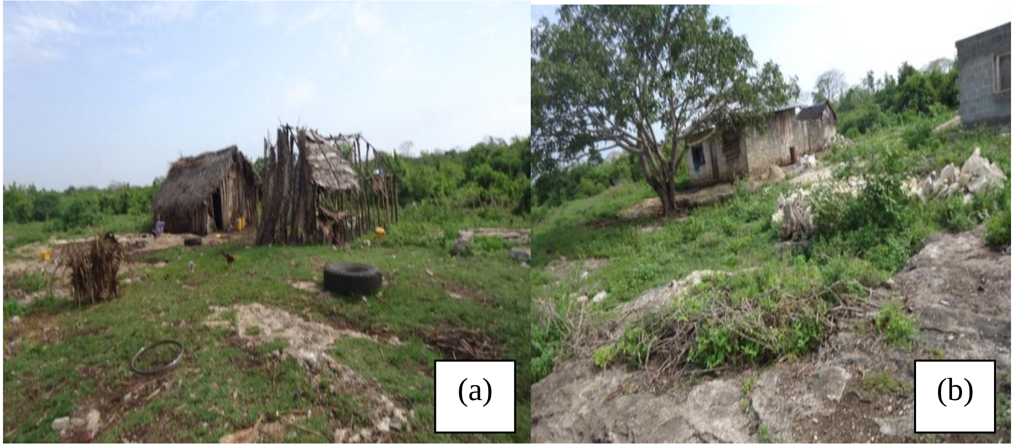

Plate 2: Informal Settlement and Shifting Cultivation in KPFR.

Furthermore, forest degradation in KPFR was linked to fuel wood collection (Plate 3a and 3b). Communities in rural areas rely heavily on firewood for cooking while urban populations use charcoal (Kombo, 2010). These results of forest degradation are consistent with other studies as reported by FAO (2006), ITTO (2001) and IPCC (2003). The World Bank (1991) reported that forest degradation caused changes in stocking and structure in most developing countries. Charcoal making contributed to serious degradation in Ghana, one of the highly affected countries. Ghana lost up to 80 % of its land cover with a 1.7 % rate of degradation from 1990 to 2000 due to human activities (ITTO, 2005).

Plate 3: Fire Wood Extraction in KPFR

Bush fire (Plate 4) was a big degradation challenge observed in the field which causes tree damage throughout the forest. Souza *et al.* (2000), FAO (2002) and FRA (2002) reported that widespread underground fire in developing countries is a pronounced cause of forest degradation of which, its disturbance is destroying both flora and fauna.

Plate 4: Wildfire in KPFR.

Forest degradation observed was probably due to probable poor forest management which led to illegal forest resources extraction, mainly by special government forces (*Vikosi vya SMZ*) and other people from neighbouring communities of KPFR. This feature of forest degradation is consistent with other studies as reported by IPCC (2006) and Lamb (1998). It was reported that for decades there has been a general failure of forest management in most developing countries due to institutional failure, poor governance and centralized approach in natural resource conservation; nonetheless, successful stories have been achieved in some countries (Bwalya, 2003).

4.2.5 Carbon dioxide emission in KPFR

Carbon dioxide equivalent (CO$_{2-}$e) provides a universal standard of measurement against different greenhouse gases that can be evaluated. The standing carbon stock obtained in 1997 was 15 tCha^{-1} and the standing carbon of this study was 11.5 tCha^{-1} indicating carbon removal of 3.5 tCha^{-1}. Thus carbon dioxide emission in KPFR from 1997 to 2011 was equivalent to 12.9 tCO2_e ha^{-1}. This was linked to forest degradation due to increasing over dependence on forest resources over time. For instance, in Zanzibar, forests provide over 90 % of the national energy supply for fire wood and charcoal and 25 % for construction materials (Kombo, 2010). Human destruction of tropical forests is estimated to contribute up to 17 % of global carbon dioxide emissions, resulting in accelerated global warming (Munish *et al*., 2010).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

The conclusion and recommendations of the research findings of the study are presented in this chapter.

5.1 Conclusion

These results indicated that KPFR is subject to degradation and hence a high potential for enhance carbon sequestration and storage through sustainable forest management. As compared to the 1997 study, the present findings were found to be comparatively lower. There was difference of nine (9) species, a decrease of 44 % in stocking (stems ha^{-1}), 56 % in basal area (m^2ha^{-1}), 48 % in volume (m^3ha^{-1}), 46 % in biomass (tha^{-1}) and 38 % carbon in ($tCha^{-1}$). More degradation occured in forest margin which had the lowest species diversity

The effect of forest degradation in KPFR had shown that many trees were found removed and this had negative influence on forest structure and carbon stock. Carbon dioxide emission had implications to climate change as the result of over cutting from human disturbance.

5.2 Recommendations

The study recommends that there is a need to upgrade the status of the surveyed forest reserve to improve its forest structure and carbon stock potential through systematic review forest policy, review institutional set up such as to involve local community in protecting forest and equally distribute forest benefit to neighboring villages to improve forest management.

To mitigate forest degradation from human disturbance, there should be a call for Government and other institution to join efforts towards taking fully responsibility and accountability to stop people cutting trees and those caught should be taken to court. This will help the forest to recover without human disturbance and thus increase carbon storage. Reduced Emissions from Deforestation and Degradation (REDD+) programme is the recommended option to mitigate carbon dioxide emissions.

REFERENCES

Ahrends, A., Burgess, N., Milledge, S., Bulling, M., Fisher, B., Smart, J., Mhoro, B. and Lewis, S. (2010). Practical waves of sequential forest degradation and biodiversity loss spreading from an African city. *Academy of Sciences USA* 107(33): 14556 – 14561.

Angelsen, A. (2012). Policies for reduced deforestation and their impact on agriultural production. *Proceedings o the National Academy of Science,* USA.
107, 19639-19644

Angelsen, A., Breakouts, M., Kanninen, M., Sills, E., Sunderlin, W. E. and Werts-Kanounnikoff, S. (2009). *Realizing REDD^{+} National strategy and policy options.* Enabling REDD through broad policy reforms.

Arild, V., Pal V., Jon P. and Ellen, S. (2009). *The REDD Direction for Reduced Forest Carbon Emissions, Biodiversity Protection and Enhanced Development.* Development of International Environment and Development Studies Noragric *Norwegian* University of Life Sciences. A desk study with special focus on Tanzania and Uganda; Noragric Report No. 51. 148 pp.

Asner, G. P., Knapp, D. E., Broadbent, E. N., Oliveira, O. J. C., Keller, M. and Silver, J. N. (2005). Selective logging in the Brazillian Amazon. *Science* 310: 480 – 482.

Atela, J. (2013) Governing REDD+: global framings versus practical evidence from the Kasigau Corridor REDD+ Project, STEPS Working Paper 55, Brighton: STEPS Centre, Kenya. 42 pp

Australian Greenhouse Office (2001). *Growing Trees and Greenhouse Sinks.* An overview for landholders. AGO in the Department of the Environmental and Heritage, Australia. 14pp.

Backéus, I., Pettersson, B., Strömquist, L. and Ruffo, C. (2006). Tree communities and structural dynamics in Miombo (*Brachystegia-Julbernadia*) Woodland, Tanzania. *Forest Ecology and Management.* 230: 171 – 178.

Baker, D. J., G. Richards, A., Grainger, P., Gonzalez, S., Brown, R. DeFries, A., Held, J., Kellndorfer, P., Ndunda, D., Ojima, P., Skrovseth, C., Souza, Jr. and F. Stolle. (2010). Achieving forst carbon information with higher certainty: a five-part plan. *Environmental Science & Policy* 13:249–260.

Barthélémy, D. and Caraglio, Y. (2007). Plant architecture: A dynamic, multilevel and comprehensive approach to plant form, structure and ontogeny. *Annals of Botany* 99: 375–407.

Barrett, C. B. K., Brandon, C., Gibson, and Gjertsen, H. (2001). Conserving Tropical Biodiversity amid Weak Institutions. *BioScience* 51(6): 497 – 502.

Brendan, G. M., Heather, K., Sandra, L. B. and David, B. L. (2008). Green carbon: the role of natural forests in carbon storage. A green carbon account of Australia’s south-eastern Eucalypt forests, and policy implications. [http://epress. anu.edu.au/green_carbon/pdf/whole_book.pdf] site visited on 25/2/2012.

Brown, S. (2003). *Measuring, Monitoring and Verification of Carbon Benefits for Forest Based Projects.* In: Capturing Carbon and Conserving Biodiversity: The Market Approach, (Edited by Swingland, I. R.), Earthscan Publications, London, UK. pp. 118 – 133.

Brown, S., Schroeder, P. and Birdsey, R. (1997). Aboveground biomass distribution of US eastern hardwood forests and the use of large trees as an indicator of forest development. *Forest Ecology and Management* 96: 37 – 47.

Brown, S. G. and Lugo, A. (1989). Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science* 35: 881 – 902.

Brown, S. (1997). *Tropical Forests and the Global Carbon Cycle:* Estimating state and change in biomass density. The role of forest ecosystems and forest management in the global carbon cycle. NATO Series. Springer Verlag, New York. pp. 135 – 144.

Brown, S. and Lugo, A. (1994). Land use and biomass changes of forests in Peninsular Malaysia during 1972 – 1982: Use of GIS analysis. Dale, V. H. (Ed.), *Effects of land use change on atmospheric* CO_2 *concentrations: Southeast Asia as a case study*. Springer Verlag, New York. pp. 135 – 144.

Bryce, J. M. (1967). *The Commercial Timber of Tanzania*. Revised by Chihongo, A.W. (1999), 2nd Edition. Tanzania Forestry Research Institute, Morogoro, Tanzania. 236pp.

Burges, N., Bahane, B., Clairs, T. Danielsen, F., Dalsgaard, S., Funder, M., Haule, C., Kabalimu, K., Kilahama, F., Edward, N., Harrison, P., Lewis, S., Lovett, J., Lyatuu, G., Andrew, R ., Meshack, C., Milledge, S., Munishi, K. T., Evarist, N., Shirima, D., Swetnam, R., Willcock, S., Williams, A. and Zahabu, E. (2010). Getting ready for REDD+ in Tanzania: A case study of progress and challenges. *Fauna and Flora International* 44(3): 339–351

Burgess, N., Butynski, T. M., Cordeiro, N. J., Doggart, N. H., Fjeldsa, J., Howell, K. M., Kilahama, F. B., Loader, S. P., Lovett, J. C., Mbilinyi, B., Menegon, M., Moyer, D. C., Nashanda, E., Perkin, A., Rovero F., Stanley, W. T. and Stuart, S. N. (2007). The biological importance of the Eastern Arc Mountains of Tanzania and Kenya. *Biological Conservation* 134: 209 – 231.

Burgess, N., Matthews, P., Evers, Y. and Woodcock, K. (2000). Human and forest interactions; non-timber uses, threats and local attitudes. In: (Edited by Burgess, N.D. and Clarke, G. P.), *Coastal Forests of Eastern Africa*. IUCN Forest Conservation Programme, Cambridge. pp. 281–301.

Bwalya, S. M. (2003). *Understanding Community-Based Wildlife Governance in Southern Africa:* A Case Study from Zambia. AJEAM-RAGEE November 2003. pp. 41 – 60.

Chamshama, S. A. O.; Mugasha, A. G. and Zahabu, E. (2004). Stand biomass and volumeestimation for miombo woodlands at Kitulangalo, Morogoro, Tanzania. *South African Forestry Journal* 200: 49 – 60.

Chidumayo, E. N. (1989). Land use, deforestation and reforestation in the Zambian Copper belt. *Land Degradation and Rehabilitation* 1: 209 – 216.

Chihongo, A. W. (1999). *The Commercial Timbers of Tanzania.* Revised by Tanzania Forestry Research Institute. ISBN 9987 04. pp. 93 – 105.

DeFries, R., Achard, F., Brown, S., Herold, M., Murdiyarso, D., Schlamadinger, B. and Carlos de Souza, C. (2006). *Reducing Greenhouse Gas Emissions from Deforestation in Developing Countries:* Considerations for monitoring and measuring GOFCGOLD/GOTS SDRN, Food and Agriculture Organization of the United Nations (FAO) Viale delle Terme di Caracalla, 00100 Working Paper. Rome, Italy. 23pp.

DCCFF (2003). *Project Proposal for the Kiwengwa-Pongwe Forest Reserve Conservation Project.* Submitted for Global Conservation Fund. August 2003. The Revolutionary Government of Zanzibar. 12pp.

Di Gregorio, A. and Jansen, L. (2000). *Land Cover Classification System.* Classification Concepts and User Manual. FAO Land and Water Development Division, Environment and Natural Resources Service, Africover – East Africa Project, Nairobi, Kenya. 30pp.

Douglas, C. M., Marcio, H. S., Carlos, M. S. and Bronson, G. (2011). *Historic Emissions from Deforestation and Forest Degradation*. Mato Grosso, Brazil. 13pp.

Fabiano, L., Karyn, T., Neil, D., Boniface, P., Japheth, K. and Mark, K. (2011). *Deforestation and CO_2 Emissions in Coastal Forest Tanzania from 1990 – 2007*. 69pp.

FAO (2000). *Global Forest Resources Assessment* 2000. United Nations Main report. FAO. Forestry Paper No.140. 479pp.

FAO (2000). *On definitions of Forest and Forest Cover Change.* Forest Resources Assessment Programme, Working Paper No. 33. Rome, Italy. 35pp.

FAO (2005). *Global Forest Resources Assessment*. Progress towards sustainable forest management. FAO Forests Paper No. 147.

FAO (2006). Director's Report to GCOS Steering Committee, Steering Committee Meeting III Document 11 Version 3, 25-27 January 2008, Rome, Italy [www.fao.org/ gtos/doc/2006-GTOS-SC/11-TCO-documents-GTOS-SC-v3.doc] site visited on 16/5/2012.

FAO (2008). Terrestrial essential climate variables for climate change assessment, mitigation and adaptation GTOS 5 [http://www.faoorg/gtos/doc/pub52.pdf] site visited on 22/3/2011.

FAO (2010). *Global Forest Resources Assessment.* Options and Recommendation for a Global Remote Sensing Survey of Forests. Forest Resources Assessment Programme Working Paper No. 141. Rome, Italy. 56pp.

FBD (2008). *Participatory Forest Management. Facts and Figures.* Forestry and Beekeeping Division (FBD), Ministry of Natural Resources and Tourism. The United Republic of Tanzania, Dar es Salaam, Tanzania.

FRA (2010). Forest Resources Assessment. *FAO for Forestry Department*, United Nations, 00153 Rome, Italy, 12 pp.

Garzula, M. and Saket, M. (2003). *Wood Volume and Woody Biomass:* Review of FRA 2000 estimates, FAO, Forest Assessment Program, Working Paper No. 69, Rome, 269pp.

Giliba, R., Boon, E., Kayombo, C., Musamba, E., Kashindye, A. and Shayo, P. (2011). Species composition, richness and diversity in Miombo Woodland of Bereku forest reserve, Tanzania Forestry Training Institute, Olmotonyi, Tanzania. *Biodiversity* 2(1): 1 – 7.

Gibbs, H. K., Brown, J. O. and Foley, J. A. (2007). *Monitoring and Estimating Tropical Forest Carbon Stocks:* Making REDD a reality. Environmental research letters for environmental studies, University of Wisconsin, University Avenue, Madison. 23pp.

Godoy, F. L., Tabor, K., Burges, N., Mbilinyi, B., Kashaigili, J. J. and Sleininger, M.K. (2012). Deforestation and Carbon dioxide emissions in Coastal Tanzania from 1990 – 2007. *Environmental Conservation* 39 (1) 62 – 71.

Gorte, R. W. and Sheikh, P. A. (2010). *Deforestation and Climate Change.* CRS Report for Congress. Congressional Research Service. 45pp.

GoZ (1997). *The Forest Resources Management and Conservation act No. 10 of 1996.* Legal Supplement (Part I) to the Zanzibar Government Gazette. pp. 167 – 215.

Grainger, A. (1993). *Controlling Tropical Deforestation.* Earths Publications Ltd., London. 310pp.

Griscom, B. D., Ganz, N., Virgilio, F., Price, J., Hayward, R., Cortez, G., Dedge, J., Hurd, F. L. and Lowenstein, B. S. (2009). *The Hidden Frontier of Forest Degradation:* A Review of Science, Policy and Practice of Reducing Degradation Emissions. The Nature Conservancy, Arlington. 76pp.

Gurney, R. K. and Raymond, L. (2008). *Targeting Deforestation Rates in Climate Change Policy:* A Preservation Pathway approach. Carbon Balance and Management. 32pp.

Hamiliton, A. C. (1998). History of resource utilization and management: The pre- colonial period. In: *Forest Uonservation in the East Usambara Mountains, Tanzania*. (Eds) Hamiliton, A. C. and Bented-Smith, R, IUCN, Gland. pp. 35 – 44.

Harrison, K. A.; Bol, R. and Bardgett, R. D. (2007). Preferences for uptake of different nitrogen forms by co-existing plant species and soil microbes in temperate grasslands. *Ecology* 88: 989–999.

Haule, E. F. and Munyuku, F. C. (1994). National forest inventory in Tanzania. *In*: Malimbwi, R. E. and Luoga, E. J. (Eds), *Proceedings of the Workshop on Information Acquisition for Sustainable Natural Forest Resources of Eastern, Central and Southern Africa*, Faculty of Forestry, SUA, Morogoro. pp. 99 – 113.

Heiskanen, J. (2006). Estimating aboveground tree biomass and leaf area index in a Mountain birch forest using ASTER satellite data. *International Journal of Remote Sensing* 27(6): 1135 – 1158.

Husch, B.; Beer, W. T. and Kershaw, A. J. (2002). *Forest Mensuration.* Fourth Edition John Wiley and Sons, London. 456pp.

Ian, J. and Rebecca, C. (2010). Carbon sequestration. Climate in Primary Industries, Forest Science Centre, West Pennant Hills. Department of Primary Industries Forest Science Centre of Excellence 121–131 Oratava Avenue, West Pennant Hills, Australia [http://en.wikipedia.org/wiki/Carbon_sequestration] site visited on 7/8/2011.

IPCC (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry*, IPCCC National Greenhouse Gas Inventories Programme, Institute for Global Environment Strategies, Kanagawa, Japan. 590pp.

IPCC (2006). IPCC guidelines for national greenhouse gas inventories [http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm] site visited on 25/4/2012.

IPCC (2007). *Definitions and Methodological Options to Inventory Emissions from Direct Human-Induced Degradation of Forests and Devegetation of other Vegetation Types.* Institute for Global Environmental Strategies, Japan. 14pp.

Ingrid, B. (2008). *Reducing Emission from Deforestation and Forest Degradation in Developing Countries:* United Nations University Institute of Advanced Studies (UNU-IAS) 6F, International Organizations Center Pacifico-Yokohama 1-1-1 Minato Mirai Nishi-ku, Yokohama, Japan. 100pp.

Isango, J. A. (2007). Stand Structure and Tree Species Composition of Tanzania Miombo Woodlands: A Case Study from Miombo Woodlands of Community Based Forest Management in Iringa District. *Forest Research Institute* 50: 43–56.

ITTO (2002). Forest restoration information service (FRIS): Concepts [http://www.unepwcmc. org/forest/restoration/fris/concepts.aspx] sited visited on 3/4/2012.

ITTO (2005). Revised ITTO criteria and indicators for the sustainable management of tropical forests including reporting format. [http://www.unepwcmc.org/forest/restoration/fris/concepts.aspx] sited visited on 3/4/2012.

ITTO (2005). Ghana country profile status of tropical forest management [http://www. itto.0rg.jp/live-server/1233/Ghana.e.pdf] site visited on 20/3/2012.

IUCN (2005). Access and benefit-sharing: Law, equity and biodiversity. Environmental Law Programme. [http://www.iucn.org/themes/law/abs01.html] site visited on 25/3/2012.

Jambiya, G., Puri, J. and Risby, L. A. (2004). *The Nature and Role of Local Benefits in GEF Programme Areas:* The Case Study of Tanzania – Zanzibar. GEF. Jozani- Chwaka Bay Conservation Project. 78pp.

Jansen, L. J. M., Bagnoli, M. and Focacci, M. (2008). Analysis of land-cover/use dynamics in Manica Province in Mozambique in a period of transition (1990–2004). *Forest Ecology and Management* 254: 308 – 326.

Kajembe, G. C. and Kessy, J. F. (2000). Joint Forest Management in Urumwa Forest Reserve, Tabora, Tanzania: A Process in the Making. In: Virtanen, P. and Nummelin, M. (Eds.) *Forests, Chiefs and Peasants in Africa: Local Management of Natural Resources in Tanzania, Zimbabwe and Mozambique*. University of Joensuu, Finland. Silva Carelica. pp. 141 – 158.

Kajembe, G. C., Shemweta, D. T. K., Luoga, E. J. and Nduwamungu, J. (2004) Incentives for Sustainable Forest Management in Tanzania. In: Shemwetta, D. T. K., Luoga, E. J., Kajembe, G. C. and Madoffe, S. S. (Eds.), *Proceedings of the IFRI East African Regional Conference, on Institutions, Incentives and Conflicts in Forest Management: A perspective.* 12 – 13 January 2004, Moshi, Tanzania. pp. 80 – 91.

Kent, M. and Coker, P. (1992) *Vegetation Description and Analysis: A practical Approach*. Ann Arbor, Belhaven Press, London. 363pp.

Kombo, Y. (2010). *Zanzibar Forest Biodiversity Versus Energy Crisis and Climate Change*. Zanzibar. 24pp.

Krebs, C. J. (1989). *Ecological Methodology*. Vegetation description and analysis: A practical approach. Belhaven Press, London. 363pp.

Lamb, D. (1998). Large-scale ecological restoration of degraded tropical forest land. The potential role of timber plantations. *Restoration Ecology* 6: 271 – 279.

Lambin, E. (1999). Monitoring forest degradation in tropical regions by remote sensing: some methodological issues. *Global Ecology and Biogeography* 8(4): 191 – 198.

Lambin, E. F., Geist H. J. and Lapers, E. (2003). Dynamics of land use and land cover change in tropical regions. *Annual Revised Environment Resources* 28: 205 – 241.

Lasco, R., Pulhin, F., Cruz, J. and Roy, S. (2005) Carbon Budgets Of Terrestrial Ecosystems In the Pantabangan-Carranglan Watershed. Environmental Forestry Programme College of Forestry and Natural Resources University of the Philippines. Working Paper No.10. Philippines. 23pp.

Leskinen, B.; Jarmo, P. V. and Mbarouk, S. (1997). *Wood Biomass Inventory of Zanzibar Island:* Commission for Natural Resources-Zanzibar/FINNIDA. 31pp.

Madoffe, S. S., Rija A. A., Midtgard, F., Katani, J. Z., Mbeyale, G., Zahabu, E., Liwenga,E., Christopher, P. C. (2012). Preliminary Assessment of Forest Structure, Management and Carbon Stocking in Tanzania Miombo Woodland 12 pp.

Mafupa, C. J. (2006). Impact of Human Disturbances in Miombo Woodlands of Igombe RiverForest Reserve, Nzega District, Tanzania. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 71pp.

Mackey, B., Keith, H., Berry, S. and Lindenmayer, D. (2008). *Green Carbon, the Role of Natural Forest in Carbon Storage:* Part 1. A green carbon account of Australia's south-eastern eucalypt forests, and policy implications. The Fenner School of Environment and Society, College of Science Australian National University Press, Australia. 41pp.

Malimbwi, R. E. and Mugasha, A. G. (2001). *Reconnaissance Inventory of Handeni Hill Forest Reserve in Tanga*. Tanzania. 28pp.

Malimbwi, R. E. and Mugasha, A. G. (2002). *Reconnaissance Timber Inventory for Handeni Hill Forest Reserve in Handeni District*. Morogoro, Tanzania. 34pp.

Malimbwi, R. E. (2003). *Inventory Reports of Ayasanda, Bubu, Duru, Endagwe, Endanachan, Gidas, Hoshan and Riroda Village Forest Reserves in Babati,* *Manyara, Tanzania*. Manyara, Tanzania: Land Management Programme, Babati District Council.

Malimbwi, R. E. (1997). *Fundamentals of Forest Menstruation.* A Compendium. Faculty of Forestry, SUA Morogoro, Tanzania. 95pp.

Maliondo, S. M. S.; Malimbwi, R. E.; Constantine, E. and Zahabu, E. (2000). Fire impact on population structure and diversity of tree species in West Usambara Camphor Zones Forest. *Journal of Tropical Forest Science* 12(3): 472 – 481.

Makame, K. (2006). Community-based natural management resources and benefit sharing in KOFR, Zanzibar. Dissertation for Award of MSc Degree at Vrije, University Brussel, 68pp.

Martin, G. J. (1996) *Comparative Ethnobotany of the Chinantec and Mixe of Sierra Norte.* University Microfilm, Ann Arbor, Michigan. Oaxaca, Mexico, 54pp.

Mbwambo, L., Valkonen, S. and Kuutti, V. (2008). Structure and dynamics of miombo woodland stands at Kitulangalo Forest Reserve, Tanzania. In Varmola, M. Valkonen. S and Tapaninen. S. (Eds.) *Research and Development for Sustainable Management of Semia-Arid Miombo Woodland in East Africa.* Working papers of Finnish Forest Research Institute. pp. 10 – 19.

McElhinney, C., Gibbons, P., Brack, C. and Bauhas, J. (2005). Forest and woodland stand structural complexity: its definition and measurement. *Forest Ecological Management* 218(3): 1 – 24.

Merino, A., Real, C., Álvarez-González, G. J. and Rodríguez-Guitián, A. M. (2007). Forest structure and C stocks in natural *Fagus sylvatica* forest in southern Europe. The effects of past management *Forest Ecology and Management* 250(3): 206 – 214.

Merry, G., Alfaro, R., Kanninen, M. and Lobovikov, M. (Eds), (2005). *Forests in the Global Balance – Changing Paradigms.* World International Union Forest Research Organizations (IUFRO), Helsinki. 318pp.

Mertz, O. (2009). Trends in shifting cultivation and the REDD mechanism. *Current Opinion in Environmental Sustainability:* Kenya; 1, 156–160.

Milledge, S. A. H. (2007). Getting REDD in Tanzania: principles, preparations and perspectives. *The Arc Journal* 24: 3 – 6.

Mills, A. and Cowling, R. (2006). Rate of carbon sequestration at two thicket restoration sites in the Eastern Cape, South Africa. *Restoration Ecology* 14(1): 38 – 49.

Mkama, J. (2010). Test participatory forest carbon assessment technique for assessing carbon stock in selected villages around Angai Village Land Forest Reserve in Liwale District. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 75pp.

Monela, G. C., Kajembe, G. C., Kaoneka, A. R. and Kowero, G. (2000). Household livelihood strategies in the miombo woodland of Tanzania: Emerging Trends. Tanzania *Journal of Forestry and Nature Conservation* 73: 17 – 33.

Mugasha, A. and Chamshama, S. (2001). *Trees Biomass and Volume Etimation of Miombo Woodlands at Kitulangalo, Morogoro*. Working Paper No. 9.

Munishi, P. K. T., Monga, S., Shirima,D. D. and Linde, S. K. (2010). The role of Miombo Woodland of Southern Highlands of Tanzania as Carbon Sink. *Journal of Ecology and the Natural Environment* 2(12): 61 – 69.

Munishi, P. K. T. (2010). *Fundamental of Ecology Compendium FBL 102 Department of Forest Biology:* Faculty of Forestry and Nature Conservation, SokoineUniversity of Agriculture, Morogoro Tanzania. 29pp.

Munishi, P. K. T., Mringi, S., Shirima. D. D. and Linda, S. K. (2010). The role of the Miombo Woodlands of the Southern Highlands of Tanzania as carbon sinks. Department of Forest Biology, *Journal of Ecology and the Natural Environment*: Vol. 2. Faculty of Forestry and Nature Conservation, Sokoine University of Agriculture. (12), pp 9

Munishi, P. T. K. and Shear, T. H. (2004). Carbon storage in Afromontane rain forests of Eastern Arc Mountains of Tanzania: Their net contribution to atmospheric Carbon. *Journal of Tropical Science* 16(1): 78 – 93.

Nabuurs, J. G., Thurig, E., Heidema, N., Armolaitis, K., Biber, P., Cienciala, E., Kaufmann, E., Makipa, R., Nilsen, P., Petritsch, R T., Rock, P. J., Schelhaas, M. J., Sievanen, R., Somogyi, Z. and Vallet, P. (2008). Hotspots of the European forests carbon cycle. *Forest Ecology and Management* 256: 194 – 200.

NAFORMA (2010). *National Forestry Resources Monitoring and Assessment of Tanzania* (NAFORMA). Field Manual Biophysical Survey. Ministry of Natural Resources and Tourism. Forestry and Beekeeping Division, Dar es Salaam, Tanzania. pp. 4 – 33.

Niles, J., Brown, S., Pretty, J., Andrew, S. and Fay, J. (2002). Potential carbon mitigation and income in developing countries from changes in use and management of agricultural and forest land. Royal Society 19pp.

Panta, M., Kyehyun, K. and Joshi, C. (2008). Temporal mapping of deforestation and forest degradation in Nepal: applications to forest conservation. *Forest Ecology and Management* 256: 587–1595.

Philip, M. S. (1994). *Measuring Tes and Frests*. Second Edition. Cab International. University Press,Cambridge. 310pp.

Pomerining, A., Biber, P., Stoyan, N. and Pretsch, H. (2000). New method of analysis and Characterization of stand structure. Approach to quantifying forest structure. *Forestry* 19: 62 – 78.

Poyry, J. (1983). *Forest Management Plan for Zanzibar Island*. Main report. Jaako Poyry Oy and FINNIDA. Helsinki. 103pp.

Richard, J. (2007). Abundance and Distribution of an alien plant Panama rubber (*Castilla elastica)* in Aman nature reserve, Tanzania. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 90pp.

Roe D.; Nelson, F. and Sandbrook, C. (2009). *Community Management of Natural Resources in Africa:* Impacts, experiences and future directions, Natural Resource Issues No. 18. International Institute for Environment and Development, London, UK. 207pp.

Ross, W. and Sheikh, P. (2010). *Deforestation and Climate Change*: Congressional research service. Specialist in Natural Resources Policy. 45pp.

Saunders, J., Elbert, J. and Nussbauma, R. (2008). *Reduced Emissions from Deforestation and Forest Degradation* (REDD): Lessons from a governance perspective. Oxford, United Kingdom. 19pp.

Souza, J., Firestone, L. and Roberts, D. (2003). Mapping forest degradation in the Eastern Amazon from SPOT 4 through spectral mixture. *Models Remote Sensing of Environment* 87: 494 – 506.

Tabor, K., Burgess, N., Mbilinyi, B., Kashaigili, J. and Steininger, K. (2010). Forest and woodland cover and change in coastal Tanzania and Kenya, 1990 to 2000. *Journal of the East African Natural History Society* 99(1): 19–45.

Terakunpisut, J., Gajaseni, N. and Ruankawe, N. (2007). Carbon sequestration potential in aboveground biomass of Thong pha phun national forest, Thailand. *Applied Ecology and Environmental Research* 5: 93 – 102.

UNEP (2006). Environmental Policy and Law, This article is a revised and updated version of the author's Bonn Open Lecture of 26 October 2005 at United Nations University's Institute. *Environment and Human Security* 36: 3 – 4.

UNEP (2008). Implementing MEA's in the decentralised context of Benin, United Nations Environment Programme.

UNFCCC (2008). *Report of the Conference of the Parties on its Thirteenth Session.* held in Bali from 3 to 15 December 2007. Bonn, Germany. 60pp.

UN-Habitat (2004). Pro-poor land management: Integrating slums into city Planning approaches, United Nations Human Settlement Programme, Nairobi, Kenya.

URT (1998). *The National Forest Policy*. Government Press, Dar es Salaam, Tanzania. 59pp.

Vatn, A., Vedeld, P., Peturson, J. G. and Stensilie, E. (2009). *The REDD Direction. the Potential of Reduced Carbon Emissions, Biodiversity Protection and Enhancement Development.* A desk study with focus on Tanzania and Uganda. Norwegian Report. Norwegian University of Life Science, Norway. 140pp.

Vatn, A. and Angelsen, A. (2009). Options for a national REDD+ architecture. In Angelsen, A. (Eds), *Realising REDD+: National Strategy and Policy options*. Bogor, Indonesia. pp. 57-74.

Watson, C., S. Mourato, and Milner-Gulland E. (2013). Uncertain emission reductions from forest conservation: REDD in the Bale Mountains, Ethiopia. *Ecology and Society* **18** (3): 6.

World Bank (2004). *Sustaining forest: Development strategies*. Washington, DC. 80pp.

Wunder, S., Engel, S. and Pagiola, S. (2008). Taking stock: A comparative analysis of payments for environmental services programs in developing and developing countries. *Ecological Economics* 65(4): 834 – 853.

Yanda, P. (2010). Economic of Climate in Tanzania. Importance of of Reducing Emmissions for Defoerstation and Forest Degradation. Institute of Resources Analysis. University of Dar es Salaam.pp33.

Zahabu, E. (2006). Case Study Handei village forest reserve, Tanzania. In Murdiyoso, D. and Skutsch, M. (Eds). *Community Forest Management as a Carbon Mitigation* Option Case Studies. Boagor, Indonesia. Center for International Forest Research. pp. 16 – 19.

Zahabu, E. and Malimbwi, R. (1998). *Structure and Composition of Tree Species in Amani Nature Reserve.* Faculty of Forestry, Record No. 67. 266pp.

Zahabu, E. (2008). Sinks and sources. A strategy to involve forest communities in Tanzania in Global climate policy. Thesis for Award of PhD Degree at University of Twente, 261pp.

APPENDICES

Appendix 1: Summary of different definitions of forest degradation according to change in forest parameters

Loss of Forest Values	Sources
Crown cover	FAO 2006,
Forest health	People & the Planet 2000 – 2008
Tree density/Stocking	Grainger 1996
Structure	ITTO 2005, IPCC 2003
Species composition	FAO 2006, Grainger 1996
Biodiversity	UNEP 2006
Reduction of capacity in service delivery:	
Carbon stocks/biomass	FAO 2006, IPCC 1996
Goods and Services	FAO 2001
Productivity	Lambin 1999, World Bank 1991
Causes:	
Harvesting	FAO 2006,
Fire	Souza *et al.*, 2003,
Logging	Castellani *et al.*, 1983
Fuel wood/timber exploitation	FAO 2006, IPCC 2003,
Wind-felling	FAO 2002, FRA 2002,
Over grazing	FAO 2006
Attacks by insects/Diseases /Plant parasites	FAO 2006
Invasive Species	FAO 2001, IUCN, 2005

Appendix 2: Above ground carbon (tCha^{-1}) for standing trees

Transect	Plots	dbh>4<10	dbh>10<20	dbh>20	Total
1	1	3.408404	0	0	3.408404
1	2	4.3383	0	0	4.3383
2	1	5.273466	0	0	5.273466
2	2	4.359952	6.551655	0	13.7793
2	3	8.041957	1.282775	0	9.324732
2	4	10.35643	7.082495	7.679889	25.11882
2	5	1.560729	5.109516	1.462151	8.132396
2	6	7.60561	0	0	7.60561
2	7	5.535547	0.649329	0	6.184876
3	1	1.319058	10.45536	0	11.77442
3	2	2.988458	1.904119	13.00022	17.89279
3	3	1.553408	5.925281	2.55882	10.03751
3	4	2.89295	6.848577	9.395731	19.13726
3	5	3.395061	6.01319	2.665822	12.07407
3	6	3.860303	2.852953	11.51901	18.23226
3	7	3.622271	1.855765	0	5.478036
3	8	2.430802	2.20658	0	4.637382
3	9	1.612635	0	0	1.612635
4	1	3.174504	2.835608	2.289691	8.299803
4	2	2.443385	5.163317	30.55023	28.15693
4	3	3.22527	10.06807	16.20426	29.4976
4	4	3.350397	11.17246	17.21923	31.74209
4	5	2.506586	4.312598	32.1167	38.93589
4	6	7.200466	4.882739	2.973602	15.05681
4	7	4.179927	4.918692	5.848297	14.94692
4	8	6.038711	7.362113	2.130872	15.5317
4	9	4.835032	2.880728	1.175492	8.891253
5	1	6.246212	10.75776		23.00397
5	2	8.247324	7.28447	4.397919	19.92971
5	3	5.564133	6.661171	2.665822	14.89113
5	4	5.447706	8.470431	15.01709	28.93523
5	5	14.83765	7.679814	5.294071	27.81154
5	6	10.04207	2.083133	0	12.1252
6	1	2.33343	3.158351	0	5.491781
6	2	3.280212	3.304689	5.290384	11.87529
6	3	4.680416	7.581583	10.04004	22.30204
6	4	2.430802	4.179304	2.360169	8.970275
6	5	1.339542	0.58614	0	1.925682
7	1	4.612562	1.166478	0	5.779041
7	2	1.135924	2.812996	14.71559	18.66451
7	3	2.158822	10.77603	17.24301	30.17787
7	4	2.526204	4.275355	4.415048	11.21661
7	5	5.683339	17.15397	0	22.83731
7	6	0	4.050237	25.97545	30.02569
7	7	2.385378	3.015937	1.619778	7.021093

Transect	Plots	dbh>4<10	dbh>10<20	dbh>20	Total
8	2	2.068863	1.677216	8.767215	12.51329
8	4	2.080332	2.591702	3.396295	8.068328
8	5	5.293633	10.21039	3.462151	8.96617
8	6	1.192689	2.091666	5.904088	9.188443
8	7	3.057934	3.476205	0	6.534139
9	2	0	0	3.008395	3.008395
9	3	0.273094	1.404029	0	1.677123
9	4	1.066448	10.32121	1.046045	12.4337
9	5	4.885784	3.14627	0	8.032054
10	1	1.738876	1.896032	0	3.634908
10	2	2.728076	0	0	2.728076
10	3	4.720672	0.716446	7.004821	12.44194
10	4	4.105687	6.231763	0	10.33745
10	5	3.669195	1.742214	0	5.411408
10	6	4.951968	0	0	4.951968
11	1	1.324438	9.076285	0	10.40072
11	2	4.037064	0	0	4.037064
11	3	9.776933	0	0	9.776933
11	4	3.021265	2.328354	0	5.349618
11	5	5.524534	1.611907	0	7.136441
11	6	4.952322	1.498482	0	6.450804
11	7	1.612635	1.057366	0	2.670001
12	2	2.504543	0	0	2.504543
12	3	1.525225	1.742214	0	3.267439
12	4	8.529759	3.061007	24.66424	25.255
12	5	4.359952	0.58614	0	4.946093
12	6	0.704509	1.709747	2.079641	3.493897
13	1	0.273094			0.273094
13	4	1.409018	0	0	1.409018
13	5	0	1.920149	0	1.920149
13	6	3.63374	2.328354		5.962094
14	1	1.465783	0	0	1.465783
14	3	6.407112	0	1.619778	7.02689
		3.537769	**3.57345**	**4.552957**	**11.5482**

Appendix 3: Above ground carbon for dead trees (tCha^{-1})

Transect	Plots	dbh>4<10	dbh>10<20	dbh>20	Total
1	1	0	0	1.259482	1.259482
1	2	1.598374	1.850177	0	3.448552
2	1	1.510255	2.684971	0	4.195226
2	2	0.459164	1.363661	2.85277	4.675596
2	3	0	4.931697	0	4.931697
2	4	1.824555	0	0	1.824555
2	5	0	0	0	0
2	6	3.608818	2.058591	0	5.667409
2	7	3.042876	0	0	5.042876
3	1	1.412486	1.380509	3.315906	6.108901
3	2	1.420513	4.095916	0	5.516429
3	3	0.573159	0	3.315906	3.889065
3	4	1.897174	0	5.834768	7.731942
3	5	0.710301	0	0	0.710301
3	6	1.590348	3.622219	0	5.212567
3	7	1.569842	1.709825	7.47426	10.75393
3	8	0.183999	0.433512	1.39915	2.01666
3	9	1.444716	0	0	1.444716
4	1	1.880364	1.31761	0	3.197974
4	2	0.662549	0.847136	1.792779	3.302464
4	3	1.569409	0	0	1.569409
4	4	1.463961	5.267761	7.883641	10.61536
4	5	0.148884	0	3.004235	3.153119
4	6	0	0.847136	0	0.847136
4	7	0.832986	2.557766	0	3.390752
4	8	1.444716	0	1.792779	3.237496
4	9	1.880364	1.681929	0	3.562293
5	1	1.0091	3.072695	0	4.081795
5	2	0	1.569409	0	1.569409
5	3	1.463961	5.267761	7.883641	14.61536
5	4	0	0	1.12855	1.12855
5	5	1.43801	0.470474	0	1.908484
5	6	0.912278	3.244939	0	4.157217
6	1	1.604799	0	0	1.604799
6	2	6.82289	3.479086	0	10.30198
6	3	5.910612	2.422911	0	8.333524

6	4	0	3.936112	7.47426	11.41037
6	5	0	2.226939	1.39915	3.626088
7	1	1.574827	1.850983	0	3.42581
7	2	0	6.792087	1.12855	7.920637
7	3	1.211077	3.704365	0	4.915442
7	4	1.211077	2.566052	1.259482	5.036611
7	5	0.298799	2.837177	3.241123	6.3771
7	6	0	0	1.175042	1.175042
7	7	1.364823	0	0	1.364823
8	2	1.131184	0	0	1.131184
8	3	0.654523	0	0	0.654523
9	2	1.090139	7.053692	3.000972	11.1448
9	3	2.510652	8.681679	0	11.19233
9	4	2.614868	7.571872	25.67901	30.86575
9	5	2.606066	4.324028	0	6.930094
10	1	4.471456	0	0	4.471456
10	2	2.493155	1.428559	0	3.921714
10	3	2.791954	1.428559	7.323038	11.54355
10	4	2.791954	4.438722	8.691483	15.92216
10	5	2.052263	2.857615	3.98132	9.891199
10	6	2.809451	8.157472	3.040414	9.00734
11	1	2.209418	4.683438	10.51043	16.40329
11	2	1.290402	0.581423	0	1.871825
11	3	0.654523	0	0	0.654523
11	4	1.375267	6.175011	0	9.550277
11	5	1.574827	1.63332	0	3.208147
11	6	1.494745	2.243658	**2.045841**	**5.6**

Appendix 4: Carbon of Standing Species

Species	**Carbon ($tCha^{-1}$)**	**Species**	**Carbon ($tCha^{-1}$)**
Mystroxylon aethiopicum	1.957	*Pittosporum viridiflorum*	0.044
Uvariodendrom kirkii	1.417	*Blighia umjugata*	0.042
Terminalia boivinii	1.112	*Ficus spp*	0.042
Olea woodiana	1.095	*Encephalartos hildebrandtii*	0.041
Diospyros consolatae	0.968	*Flueggea virosa*	0.04
Ozoroa obovata	0.737	*Vernonia zanzibariensis*	0.039
Mimusops obtusifolia	0.559	*Turraea floribunda*	0.037
Eugenia capensis	0.448	*Croton pseudopulechellus*	0.034
Maytenus mossambiceansis	0.443	*Teclea nobilis*	0.034
Ficus ingens	0.32	*Syzygium cuminii*	0.033
Euclea natalensis	0.283	*Apporrhiza paniculata*	0.032
Polysphaeria parvifolia	0.259	*Carpediaptera africana*	0.03
Macphersonia gracilis	0.147	*Flacourtia indica*	0.028
Lannea schweinfurthi	0.142	*Dichrostachys cinera*	0.024
Pyrostia bibracteata	0.123	*Monanthotaxis fornicata*	0.024
Rhus natalensis	0.118	*Mangifera indica*	0.024
Rhoicissus revoilii	0.109	*Monodora grandidieri*	0.024
Grewia bicolor	0.099	*Melia azadrach*	0.019
Eudea racemosa	0.085	*Apodytes dimidiata*	0.016
Milletia usaramensis	0.081	*Ficus exasperata*	0.015
Acacia auriculiformis	0.075	*Adenia gummifera*	0.014
Strychnos angolensis	0.072	*Dalbegia vaccinifolia*	0.01
Bridelia carthatica	0.069	*Annona senegalensis*	0.008
Drypetes natalensis	0.065	*Mallotus oppositifolius*	0.008
Sorindeia madagascariensis	0.059	*Rhus longipes*	0.007
Canthium mombasica	0.056	*Sterculia africana*	0.007
Ficus lutea	0.055	*Discorea zanzibariensis*	0.005
Sideroxylon inerme	0.054	*Allophylus pervillei*	0.003
Harrisonia abyssinica	0.046	*Salacia elegans*	0.003
Suregada zanzibariensis	0.045		0
Sub Total	11.098 ($tCha^{-1}$)		0.687 ($tCha^{-1}$)
Grand Total		**11.7 ($tCha^{-1}$)**	

Appendix 5: Carbon removed by species

Species	carbon (tCha^{-1})	Species	Carbon (tCha^{1})
Terminalia boivinii	0.64	*Vernonia zanzibariensis*	0.05
Diospyros consolatae	0.63	*Ficus ingens*	0.05
Mimusops obtusifolia	0.60	*Suregada zanzibariensis*	0.04
Mystroxylon aethiopicum	0.56	*Hoslundia opposita*	0.04
Milletia usaramensis	0.40	*Harrisonia abyssinica*	0.04
Ozoroa obovata	0.38	*Canthium mombasica*	0.02
Macphersonia gracilis	0.36	*Euclea racemosa*	0.02
Polysphaeria parvifolia	0.29	*Bridelia carthatica*	0.02
Olea woodiana	0.24	*Markhamia lutea*	0.02
Maytenus mossambicensis	0.23	*Bersama abyssinica*	0.02
Lannea schweinfurthii	0.19	*Strychnos angolensis*	0.01
Eugenia capensis	0.16	*Flueggea virosa*	0.01
Euclea natalensis	0.13	*Annona senegalensis*	0.01
Blighia unijugata	0.10	*Ficus scasselatii*	0.01
Rhus natalensis	0.09	*Grewia bicola*	0.01
Teclea nobilis	0.08	*Allophylus pervillei*	0.01
Pyrostia bibracteata	0.07	*Carpediaptera africana*	0.01
Croton pseudopulchellus	0.05	*Ficus exasperate*	0.01
Sorindeia madagascariensis	0.05	*Rhus longipes*	0.00
Sub Total	**5.25 (tCha^{-1})**		**0.40 (tCha^{-1})**
Grand Total	**5.65 (tCha-1)**		

Appendix 6: Kiwengwa Pongwe Forest Species

Tree Code	Local name	Botanical name	Family	Category
1	Mpilipili doria	*Sorindeia madagascariensis*	Anacardiaceae	Tree
2	Mkuyu Kupe	*Terminalia boivinii*	Combretaceae	Tree
3	Mnyevuu	*Mimusops obtusifolia*	Sapotaceae	Tree
5	Mlapaa	*Polysphaeria parvifolia*	Rubiaceae	Tree
6	Mjoma	*Macphersonia gracilis*	Sapindaceae	Tree
7	Mchakuzi	*Monanthotaxis fornicata*	Annonaceae	Liana
8	Mkunguni	*Grewia bicolor*	Tiliaceae	Tree
9	Mkaaga	*Eugenia capensis*	Myrtaceae	Tree
10	Mtowe	*Ancylobotrys petersiana*	Aposianaceae	Liana
11	Mkole	*Grewia bicolor*	Tiliaceae	Tree
12	Mbibikuu	*Synaptolepis kirkii*	Thymlacaceae	Liana
13	Mbunduki	*Ehretia amoena*	Boraginaceae	Tree
14	Mchofu	*Monodora grandidieri*	Annonaceae	Liana
15	Kifugu	*Mystroxylon aethiopicum*	Celastraceae	Tree
16	Mpwipwi	*Salacia elegans*	Celastraceae	Liana
17	Mzambarau	*Syzygium cuminii*	Myrtaceae	Tree
18	Mngombe	*Ozoroa obovata*	Anacardiaceae	Tree
19	Mtamagoa	*Turraea floribunda*	Meliaceae	Shrub
20	Mkonge	*Synaptolepis kirkii*	Thymelaeaceae	Tree
21	Mtarawanda	*Markamia lutea*	Bignonaceae	Tree
23	Mchanjavuaa	*Lecaniodiscus fraxinifolia*	Sapindaceae	Tree
24	Msasa	*Ficus exasperata*	Moraceae	Tree
25	Mnywa/Mdakakomba	*Toddalia asiatica*	Rutaceae	Liana
26	Mtule	*Ocimum suave*	Labiatae	Shrub
27	Mkonge dume	*Canthium mombasica*	Rubiaaceae	Tree
28	Haungongwa	*Psychotria mahonii*	Rubiaceae	Tree
29	Mkuu kilemba	*Blighia unijugata*	Sapindaceae	Tree
30	Mbuyu	*Adansonia digitata*	Bombacaceae	Tree
31	Mchembelele	*Apporrhiza paniculata*	Sapindaceae	Tree
32	Mtongo	*Rhoicissus revoilii*	Vitaceae	Liana
33	Mchonjo	*Allophylus pervillei*	Sapindaceae	Tree
34	Kinanga chenge	*Allophylus spp*	Sapindaceae	Shrub
35	Mlaninga	*Ficus ingens*	Moraceae	Tree
36	Kiviza	*Cyphostemma spp*	Vitaceae	Climber
37	Mgwede	*Encephalartos hildebrandtii*	Zamiaceae	Shrub
38	Mkururu	*Diospyros consolatae*	Ebenaceae	Tree
39	Msiliza	*Euclea natalensis*	Ebenaceae	Tree
40	Mtunda	*Melia azadrach*	Malvaceae	Tree
41	Mdimu msitu	*Suregada zanzibariensis*	Euphorbeaceae	Tree
42	Mchakati	*Acalypha fruticosa*	Euphorbeaceae	Shrub
43	Mlapaa dume	*Polysphaeria multiflora*	Rubiaceae	Tree

Tree Code	**Local name**	**Botanical name**	**Family**	**Category**
44	Mnusi	*Maytenus mossambiceansis*	Celastraceae	Tree
45	Mchopaka	*Mystroxylon aethiopicum*	Celastraceae	Tree
46	Mpesu	*Trema orientalis*	Ulmaceae	Tree
47	Muavikali	*Clausena anisata*	Rutaceae	Tree
48	Mfurugudu	*Brexia madagascariencis*	Saxifragaceae	Tree
49	Mkwamba	*Flueggea virosa*	Euphorbeaceae	Tree
50	Mkaati	*Bridelia carthatica*	Euphorbeaceae	Tree
51	Mtukutu	*Vernonia zanzibariensis*	Compositae	Tree
52	Mviongozi	*Dalbegia vaccinifolia*	Leguminoceae	Liana
53	Mdaa	*Euclea racemosa*	Ebenaceae	Tree
54	Mkweche	*Euphorbia nyikae*	Euphorbiaceae	Shrub
55	Mpinga/Mfupapo	*Lannea schweinfurthii*	Anacardiaceae	Tree
56	Mtonga	*Strychnos angolensis*	Loganiaceae	Tree
57	Mnunuu	*Hoslundia opposita*	Verbenaceae	Shrub
58	Mkumba	*Rhus natalensis*	Anacardiaceae	Tree
59	Muongoti	*Apodytes dimidiata*	Icacinaceae	Tree
60	Muoza	*Sterculia africana*	Sterculiaceae	Tree
61	Mfuu	*Vitex doniana*	Verbenaceae	Tree
62	Mpinga waume	*Senna petersiana*	Fabaceae	Tree
63	Kuche la Simba	*Harrisonia abyssinica*	Simaroubaceae	Shrub
64	Kidaramba	*Olea woodiana*	Oleaceae	Shrub
65	Mchunga	*Lauracia cornuta*	Compositae	Herb
66	Mwembe	*Mangifera indica*	Anacardiaceae	Tree
67	Mbaazi mwitu	*Psiadia puncutulata*	Compositae	Tree
68	Mkalamu	*Gloriosa superba*	Liliaceae	Climber
69	Mziwa ziwa	*Euphorbia hirta*	Euphorbeaceae	Herb
70	Mtunda kanga/Mshita kanga	*Cassytha filiformis*	Lauraceae	Climber
71	Mtunguja	*Solannum incanum*	Solanaceae	Herb
72	Mgole maji	*Trichilia emetica*	Meliaceae	Tree
73	Mti mafuta	*Psychotria goetzel*	Rubiaceae	Shrub
74	Mchofu	*Monodora grandidieri*	Annonaceae	Tree
75	Mziindigwa	*Parquetina nigrescens*	Ascelepiadaceae	
76	Mpava	*Cyperus rotundus*	Cyperaceae	Tree
77	Mrija	*Clerodendrum myricoides*	Verbenaceae	Shrub
78	Mgeuka/Mfusho	*Croton pseudopulchellus*	Euphorbeaceae	Tree
79	Jimbi kuti	*Polypodium scolipendria*	Cyatheaceae	Herb
80	Mpande	*Pittosporum viridiflorum*	Pittsporaceae	Tree
81	Mkaa	*Aleurite molucana*	Euphorbiaceae	
82	Mtumbaku	*Vernonia zanzibarica*	Compositae	
83	Mzabibu mwitu	*Cyphostemma adenocaule*	Vitaceae	Climber
85	Mlala ngawa	*Olea woodiana*	Oleaceae	Tree
86	Mchengele	*Rhus longipes*	Anacardiaceae	Shrub
87	Mkaakaa	*Bridelia carthatica*	Euphorbeaceae	Tree

Tree Code	**Local name**	**Botanical name**	**Family**	**Category**
88	Muwanga	*Carpediaptera africana*	Tiliaceae	Tree
89				
90	Mbebeta/Mpepe	*Dodonaea viscosa*	Sapindaceae	Shrub
91	Mgunga	*Dichrostachys cinera*	Leguminosae	Tree
92	Mduyuduyu	*Paulinia pinnata*	Sapindaceae	Climber
93	Mbuyu mwaka	*Deinbollia borbonica*	Sapindaceae	Tree
94	Mgo	*Flacourtia indica*	Flacourtiaceae	Tree
95	Mpera	*Psidium guajava*	Myrtaceae	Tree
96	Kikwayakwaya	*Stachytarpheta jamaicencis*	Verbenaceae	Herb
97	Mlashore	*Tarenna pavettoides*	Rubiaceae	Shrub
98	Mtumbua	*Dovyalis microcalyx*	Flacourtiaceae	Tree
100	Muwatawata	*Boerhavia diffusa*	Nyctaginaceae	Tree
101	Tubwi	*Discorea zanzibariensis*	Dioscoreaceae	Climber
102	Mbebeta uvundo	*Clerodendrum glabrum*	Verbenaceae	Tree
103	Mpapai mwitu	*Cussonia zimmermannii*	Araliaceae	Tree
104	Ukoka/nyasi	*Panicum trichocladum*	Gramineae	Herb
105	Mgongo	*Sclerocarya birrea*	Anacardiaceae	Tree
106	Mfagio	*Sida acuta*	Malvaceae	Shrub
107	Mkandika/Mngujinguji	*Sideroxylon inerme*	Sapotaceae	Tree
108	Mwanga kwao	*Bersama abyssinica*	Melianthaceae	Tree
109	Mgorowenzi	*Adenia gummifera*	Passifloraceae	Liana
110	Mtopetope	*Annona senegalensis*	Annonaceae	Tree
111	Mkeshia	*Acacia auriculiformis*	Fabiaceae	Tree
112	Mwafu	*Jasminum fluminense*	Oleaceae	Climber
113	Mtamtam makunde	*Cassia abbreviata*	Caesalpinioaceae	Tree
114	Mkangara shamba	*Rapanea melanophloeos*	Myrsinaceae	Tree
115	Mkonge pori	*Sansevieria kirkii*	Agavaceae	Herb
116	Mlakunguru	*Lantana camara*	Labiatae	Tree
117	Mjafari	*Zanthoxylum holtzianum,*	Rutaceae	
118	Mchofu mkuu/dume	*Uvariodendrom kirkii*	Annonaceae	Tree
119	Mvunja chuma/Mchunga mwitu	*Teclea nobilis*	Rutaceae	Tree
120	Mwango	*Rauvolfia mombasiana*	Apocynaceae	Tree
121	Kongwa	*Commelina diffusa*	Commelinaceae	Herb
122	Uwanga dume	*Gonatopus boivinii*	Araceae	Herb
123	Mcheza mwitu	*Teclea simplicifolia*	Rutaceae	Tree
124	Mpera mwitu	*Rawsonia lucida*	Flacourtaceae	Tree
125	Mbarika	*Ricinus communis*	Euphorbeaceae	Shrub

Appendix 7: Distribution of IVI by the order of species

Species name	BA (m^2ha^{-1})	Frequency	Density (N/ha)	RBA	RF	RD	IVI	IVI%
Acacia auriculiformis	0.56	10	140.85	0.00	0.01	0.01	0.01	0.79
Adenia gummifera	0.54	1	14.08	0.00	0.00	0.00	0.00	0.14
Allophylus pervillei	0.03	1	14.08	0.00	0.00	0.00	0.00	0.08
Annona senegalensis	0.19	1	14.08	0.00	0.00	0.00	0.00	0.10
Apodytes dimidiata	0.32	1	14.08	0.00	0.00	0.00	0.00	0.11
Apporrhiza paniculata	0.23	4	56.34	0.00	0.00	0.00	0.00	0.31
Bligia unjjugata	1.47	3	42.25	0.01	0.00	0.00	0.00	0.40
Bridelia carthatica	1.57	6	84.51	0.01	0.01	0.01	0.01	0.63
Canthium mombasica	1.04	6	84.51	0.00	0.01	0.01	0.01	0.56
Carpediaptera africana	0.50	4	56.34	0.00	0.00	0.00	0.00	0.35
Croton pseudopulchellus	0.28	8	112.68	0.00	0.01	0.01	0.01	0.61
Dichrostachys cinera	0.35	4	56.34	0.00	0.00	0.00	0.00	0.33
Diospyros consolatae	18.55	68	43.00	0.07	0.07	0.07	0.07	7.25
Discorea zanzibariensis	0.04	1	14.08	0.00	0.00	0.00	0.00	0.08
Drypetes natalensis	0.67	11	154.93	0.00	0.01	0.01	0.01	0.87
Encephalartos hildebrandtii	1.28	1	14.08	0.00	0.00	0.00	0.00	0.24
Euclea natalensis	3.08	53	74.20	0.01	0.06	0.06	0.04	4.18
Euclea racemosa	1.01	9	126.76	0.00	0.01	0.01	0.01	0.77
Eugenia capensis	4.96	55	22.00	0.02	0.06	0.06	0.05	4.57
Ficus exasperate	0.13	4	56.34	0.00	0.00	0.00	0.00	0.30
Ficus ingens	7.80	24	33.80	0.03	0.03	0.03	0.03	2.72
Ficus lutea	1.19	6	84.51	0.00	0.01	0.01	0.01	0.58
Ficus spp	0.57	7	98.59	0.00	0.01	0.01	0.01	0.57
Flacourtia indica	0.44	6	84.51	0.00	0.01	0.01	0.00	0.49
Flueggea virosa	0.31	7	98.59	0.00	0.01	0.01	0.01	0.54
Grewia bicola	2.29	7	98.59	0.01	0.01	0.01	0.01	0.79
Harrisonia abyssinica	0.66	1	14.08	0.00	0.00	0.00	0.00	0.16
Lannea schweinfurthii	7.04	6	84.51	0.03	0.01	0.01	0.01	1.33
Macphersonia gracilis	8.29	56	27.38	0.03	0.06	0.06	0.05	5.07
Melia azadrach	0.69	1	14.08	0.00	0.00	0.00	0.00	0.16
Milletia usaramensis	1.20	10	140.85	0.00	0.01	0.01	0.01	0.87
Mimusops obtusifolia	11.97	49	21.56	0.05	0.05	0.05	0.05	5.04
Monanthotaxis fornicata	0.16	2	28.17	0.00	0.00	0.00	0.00	0.16
Monodora grandidieri	0.45	3	42.25	0.00	0.00	0.00	0.00	0.27
Mystroxylon aethiopicum	51.64	149	74.95	0.20	0.16	0.16	0.17	17.29
Olea woodiana	31.68	42	34.80	0.12	0.05	0.05	0.07	7.08
Ozoroa obovata	21.70	38	23.04	0.08	0.04	0.04	0.06	5.51
Pittosporum viridiflorum	1.36	1	14.08	0.01	0.00	0.00	0.00	0.25
Polysphaeria parvifolia	2.37	11	28.17	0.01	0.01	0.01	0.01	1.09
Sideroxylon inerme	1.20	5	70.42	0.00	0.01	0.01	0.01	0.51

Species name	**BA (m^2ha^{-1})**	**Frequency**	**Density (N/ha)**	**RBA**	**RF**	**RD**	**IVI**	**IVI%**
Sorindeia madagascariensis	0.53	8	112.68	0.00	0.01	0.01	0.01	0.64
Sterculia africana	0.16	1	14.08	0.00	0.00	0.00	0.00	0.09
Strychnos angolensis	1.10	6	84.51	0.00	0.01	0.01	0.01	0.57
Suregada zanzibariensis	0.34	8	112.68	0.00	0.01	0.01	0.01	0.62
Syzygium cuminii	0.70	3	42.25	0.00	0.00	0.00	0.00	0.30
Teclea nobilis	0.35	6	84.51	0.00	0.01	0.01	0.00	0.47
Terminalia boivinii	32.07	88	30.98	0.12	0.09	0.09	0.10	10.41
Turraea floribunda	0.24	3	42.25	0.00	0.00	0.00	0.00	0.25
Uvariodendron kirkii	21.68	1	14.08	0.08	0.00	0.00	0.03	2.86
Vernonia zanzibariensis	0.18	5	70.42	0.00	0.01	0.01	0.00	0.38

Appendix 8: Distribution of Species Diversity of Plots by Distance in KPFR

Plots	Distance	Shannon Index	Plots	Distance	Shannon Index	Plots	Distance	Shannon Index
Plot 1	50	0.60	Plot 31	600	1.92	Plot 61	300	1.3
Plot 2	300	0.76	Plot 32	900	1.79	Plot 62	600	1.3
Plot 3	50	0.00	Plot 33	600	1.56	Plot 63	900	2.5
Plot 4	50	1.42	Plot 34	300	1.26	Plot 64	600	2.2
Plot 5	300	1.92	Plot 35	50	1.49	Plot 65	300	1.1
Plot 6	600	0.23	Plot 36	300	1.71	Plot 66	50	2.0
Plot 7	900	1.76	Plot 37	600	1.79	Plot 67	300	1.7
Plot 8	600	1.85	Plot 38	300	1.61	Plot 68	600	1.8
Plot 9	300	1.06	Plot 39	50	1.04	Plot 69	900	1.6
Plot 10	50	1.19	Plot 40	50	1.21	Plot 70	600	1.2
Plot 11	50	1.58	Plot 41	300	2.25	Plot 71	300	2.3
Plot 12	300	1.47	Plot 42	600	1.50	Plot 72	50	1.5
Plot 13	600	1.08	Plot 43	900	1.59	Plot 73	50	0.0
Plot 14	900	2.87	Plot 44	600	1.52	Plot 74	300	1.4
Plot 15	1200	0.98	Plot 45	300	1.49	Plot 75	600	0.7
Plot 16	900	1.96	Plot 46	50	0.00	Plot 76	900	1.9
Plot 17	600	0.87	Plot 47	50	0.00	Plot 77	600	2.1
Plot 18	300	0.45	Plot 48	300	1.73	Plot 78	300	1.4
Plot 19	50	0.56	Plot 49	600	1.52	Plot 79	50	0.0
Plot 20	50	2.21	Plot 50	900	1.75	Plot 80	50	0.0
Plot 21	300	1.86	Plot 51	1200	1.83	Plot 81	300	0.0
Plot 22	600	1.92	Plot 52	600	1.85	Plot 82	600	1.9
Plot 23	900	1.84	Plot 53	300	0.64	Plot 83	900	0.6
Plot 24	1200	2.41	Plot 54	50	0.60	Plot 84	300	1.1
Plot 25	900	1.16	Plot 55	50	0.00	Plot 85	50	0.0
Plot 26	600	1.48	Plot 56	300	0.00	Plot 86	50	0.7
Plot 27	300	1.61	Plot 57	600	2.69	Plot 87	300	1.1
Plot 28	50	1.17	Plot 58	300	1.12	Plot 88	50	0.3
Plot 29	50	1.81	Plot 59	50	2.48			
Plot 30	300	1.63	Plot 60	50	1.60			
		1.39			1.39			1.20
					Mean 1.34			

Appendix 8: Shannon Index by species

Tree Species	**Frequent**	N	pi	nlogp	Shannon Index
Acacia auriculiformis	9	949	0.00948367	-4.65818	-0.0442
Adenia gummifera	1	949	0.00105374	-6.85541	-0.0072
Allophylus pervillei	3	949	0.00316122	-5.7568	-0.0182
Annona sinegalensis	1	949	0.00105374	-6.85541	-0.0072
Apodytes dimidiata	1	949	0.00105374	-6.85541	-0.0072
Apporrhiza paniculata	4	949	0.00421496	-5.46912	-0.0231
Bligia unijugata	3	949	0.00316122	-5.7568	-0.0182
Bridelia carthatica	6	949	0.00632244	-5.06365	-0.0320
Canthium mombasica	6	949	0.00632244	-5.06365	-0.0320
Carpediaptera africana	4	949	0.00421496	-5.46912	-0.0231
Croton pseudopulchellus	8	949	0.00842993	-4.77597	-0.0403
Dalbegia vaccinifolia	2	949	0.00210748	-6.16226	-0.0130
Dichrostachys cineria	2	949	0.00210748	-6.16226	-0.0130
Diospyros consolatae	73	949	0.07692308	-2.56495	-0.1973
Discorea zanzibariensis	1	949	0.00105374	-6.85541	-0.0072
Drypetes natalensis	11	949	0.01159115	-4.45751	-0.0517
Encephalartos hildebrandtii	1	949	0.00105374	-6.85541	-0.0072
Euclea natalensis	49	949	0.0516333	-2.96359	-0.1530
Euclea racemosa	11	949	0.01159115	-4.45751	-0.0517
Eugenia capensis	54	949	0.056902	-2.86642	-0.1631
Ficus exasperata	4	949	0.00421496	-5.46912	-0.0231
Ficus ingens	44	949	0.04636459	-3.07122	-0.1424
Ficus lutea	13	949	0.01369863	-4.29046	-0.0588
Flacourtia indica	6	949	0.00632244	-5.06365	-0.0320
Flueggea virosa	7	949	0.00737619	-4.9095	-0.0362
Grewia bicolor	17	949	0.01791359	-4.9095	-0.0879
Harrisonia abyssinica	2	949	0.00210748	-6.16226	-0.0130
Lannea schweinfurthii	6	949	0.00632244	-5.06365	-0.0320
Macphersonia gracilis	35	949	0.03688093	-3.30006	-0.1217
Mallotus oppositifolius	1	949	0.00105374	-6.85541	-0.0072
Mangifera indica	3	949	0.00316122	-5.7568	-0.0182
Maytenus mossambiceansis	48	949	0.05057956	-2.98421	-0.1509
Melea azadrach	1	949	0.00105374	-6.85541	-0.0072
Milletia usaramensis	10	949	0.01053741	-4.55282	-0.0480
Mimusops obtusifolia	46	949	0.04847208	-3.02677	-0.1467
Monanthotaxis fornicata	14	949	0.01475237	-5.46912	-0.0807
Monodora grandidieri	4	949	0.00421496	-5.46912	-0.0231
Mystroxylon aethiopicum	151	949	0.15911486	-1.83813	-0.2925
Olea woodiana	88	949	0.09272919	-2.37807	-0.2205
Pittosporum viridiflorum	1	949	0.00105374	-6.85541	-0.0072
Polysphaeria parvifolia	40	949	0.04214963	-3.16653	-0.1335
Pyrostia bibracteata	15	949	0.01580611	-4.14736	-0.0656
Rhoicissus revoilii	20	949	0.02107482	-3.85968	-0.0813
Rhus longipes	1	949	0.00105374	-6.85541	-0.0072

Rhus natalensis	8	949	0.00842993	-4.77597	-0.0403
Rhus natalensis	8	949	0.00842993	-6.16226	-0.0519
Salacia elegans	1	949	0.00105374	-6.85541	-0.0072
Sideroxylon inerme	5	949	0.0052687	-5.24597	-0.0276
Sorindeia madagascariensis	8	949	0.00842993	-4.77597	-0.0403
Sterculia africana	1	949	0.00105374	-6.85541	-0.0072
Strychnos angolensis	6	949	0.00632244	-5.06365	-0.0320
Suregada zanzibariensis	18	949	0.01896733	-4.77597	-0.0906
Syzygium cuminii	5	949	0.0052687	-5.7568	-0.0303
Teclea nobilis	6	949	0.00632244	-5.06365	-0.0320
Terminalia boivinii	83	949	0.08746048	-2.43657	-0.2131
Turraea floribunda	3	949	0.00316122	-5.7568	-0.0182
Uvariodendrom kirkii	10	949	0.01053741	-6.85541	-0.0722
Vernonia zanzibariensis	11	949	0.01159115	-4.45751	-0.0517
	949				**0.059**

Appendix 9: Data collection form for standing trees species

KIWENGWA PONGWE FOREST RESERVE INVENTORY, 2011/2012

TREES FORM

Coordinate
X …………………………
Y. …………………………

Form No. ……… Transect No. ……… Plot No. ………….. Date ……………..

Plot Radius	**Tree Code**	**Species Name**		**Stump diameter classes**				**Height**	**Remarks**
		Local	**Botanical**	**<5**	**>5 - 10**	**>10 - 20**	**>20**	(m)	

Comment ………………………………………………………………………………..
……………………………………………………………………………….
……………………………………………………………………………….

Appendix 10: Data collection form for stumps

KIWENGWA PONGWE FOREST RESERVE INVENTORY, 2011/2012

STUMP FORM

Coordinate
X …………………………
Y. …………………………

Form No. ……… Transect No. ……… Plot No. ………….. Date ……………

Plot Radius	Tree Code	Species Name		Stump diameter classes				New	Old	Remarks
		Local	Botanical	<5	>5 - 10	>10 - 20	>20			

Comment
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