EFFECTS OF DEGRADATION ON CARBON STOCKS AND STRUCTURE OF MIOMBO WOODLANDS: A CASE STUDY OF MAPOGORO WOODLANDS, CHUNYA DISTRICT, TANZANIA

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ABSTRACT

Miombo woodlands form an integral part of the rural landscape in Tanzania and play crucial role in providing wide range of products and ecological services including carbon sequestration. Woodlands and forests in Tanzania are going through great changes due to encroachment which cause a loss of approximately 420 000ha of forests and woodlands per year. This study aimed at assessing the effects of degradation on carbon stocks and stand structure of miombo woodlands in southern Tanzania. Data were collected from 100 rectangular plots (40m×20m), 50 plots in Manga Reserve and 50 in Mapogoro General land. Tree stump diameter, diameter at breast height (DBH), tree height and local and botanical names were recorded. Analysis was done by using Excel spread sheet and R software. Results showed that gradual tree removal from the woodland contributed to a loss of 3.4±0.9 t C ha^{-1} equivalent to 12.5±3.3 tCO$_2$e ha^{-1} and 3.91±0.1 t C ha^{-1} equivalent to 14.3±0.4 t CO$_2$e ha^{-1} in Manga Reserve and Mapogoro general land, respectively. There was no significant difference in carbon loss between the two woodlands (p=0.05) despite being under different management regimes. Standing volume was 33±0.3 m^{3}ha^{-1} and 28±2.9 m^3 ha^{-1} in Manga Reserve and Mapogoro general Land respectively. Basal area was 5.0±0.3 m^{2}ha^{-1} and 4.4±2.9 m^{2}ha^{-1} in the Manga reserve and Mapogoro General land respectively. Stem size distribution showed a reverse J shape implying active regeneration of the miombo woodlands. The annual wood removal was estimated at 6.63±3.0 m^3 ha^{-1} and 8.2±2.2 m^3 ha^{-1} in Manga reserve and Mapogoro general land, respectively which exceeds the mean annual increment (MAI) of miombo 1.88-4.35 m^3 ha^{-1} year^1. There is a substantial carbon emission from the Miombo woodlands resulting from anthropogenic activities which is a threat to climate change mitigation through forest management. Managing the miombo woodland carbon stocks in Tanzania and elsewhere for reduction of Co$_2$ emissions and climate change mitigation requires rigorous effort to reduce human related degradation.

DECLARATION

I, Thomas Corodius Sawe, 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.

17/06/2013.

Thomas Corodius Sawe
(M. Sc. Candidate)

Date

The above declaration is confirmed by

19.06.2013

Prof. P.K.T. Munishi
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DEDICATION

This work is dedicated to my parents; Jane Sawe and my late father Mr. Corodius Thomas Sawe who due to their love for me, formed me into who I am; to my grandmother Elinaike Thomas Sawe who valued education and sent me to school, the fruit of which is this work so dearly complete.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

Agb	Above ground biomass
Agc	Above ground carbon
BD	Stump Diameter
CCIAM	Climate Change Impact Adaptation and Mitigation Programme
CHAPOSA	Charcoal Potential in Southern Africa
Co_2	Carbon dioxide
Dbh	Diameter at breast height
DRC	Democratic Republic of Congo
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GPS	Geographical Position System
ID	Index of Diversity
MAI	Mean Annual Increment
MNRT	Ministry of Natural Resources and Tourism
PFM	Participatory Forest Management
REDD	Reduced Emissions from Degradation and Deforestation
SPH	Stems per Hectare
TFCG	Tanzania Conservation Group
TFCG	Tanzania Forestry Conservation Group
UNFCCC	United Nation Framework for Climate Change Convention
URT	United Republic of Tanzania
VPO	Vice President Office

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

The Miombo region covers between 2.7 and 3.6 million km^2 in 11 countries of Eastern and Southern Africa. Miombo woodland are biologically rich and diverse with around 4590 plant species confined to this area, together with 35 endemic mammals, 51 endemic birds, 52 endemic reptiles, 25 endemic amphibians and an unknown number of endemic invertebrates (Bond *et al.,* 2010). Approximately 100 million people live in miombo region of which about 75 million are poor and live in rural areas (Campbell *et al*., 2007). To the rural poor, miombo woodlands are a valuable resource providing among others an effective safety net in times of distress and stress. However, many urban residents also use a range of goods from the woodlands, such as fire wood, charcoal, fruits and mushroom and there is a steady flow of goods and services between rural and urban areas (Bond *et al.,* 2010).

According to Mnangwone (1999) in Isango (2007), a National land cover and land use reconnaissance carried out in 1996 reported that miombo woodlands cover 374 356 km^2 or 93.2% of total forest area of Tanzania.These woodlands are a major source of woodfuel, construction poles, food (game, meat, fruits, and honey) and traditional medicines. Miombo also support agriculture (e.g. tobacco growers use wood biomass from miombo for processing their tobacco) (Bond *et al.,* 2010).

Despite the fact that miombo woodlands supports the livelihood of communities in rural and urban areas by supplying charcoal and other products, they are facing great pressure from the users resulting into unsustainable utilization.according to URT (2006), Tanzania population increase at an annual rate of 2.9% which has also increased consumption of charcoal, fuel wood and other products from the woodland (Malimbwi and Zahabu, 2009). According to the 2002 population census report, Tanzania had more than 34 million people and 99% of these are from mainland, which is about four times population during independence. The 2012 National Census reported that the population had increased to 44.9 million, an annual average of 1 million over ten years (URT, 2013). With such a high rate of population increase, the forest degradation and deforestation rate can be significantly felt due to increase in demand of wood and non-wood based products.

The average annual rate of woodland loss in the miombo region in Africa varies between 0.2 percent and 1.7 % per year although statistics are weak and do not include degradation (Bond *et al.,* 2010). The highest estimate for the miombo region is for Zambia, where deforestation and forest degradation across the whole country is estimated to contribute 3 per cent to total Green House Gas production from deforestation (Bond *et al*., 2010).

In Tanzania rate of forest degradation and deforestation has been differently reported by scholars, and it is approximated to vary from 130 000 ha/year to 500 000ha/ year (MNRT, 1998, FAO, 2010). Most of the woodlands are found on General lands where nobody controls the access to the resource and hence causes the miombo woodlands to be stressed for high demand of its valuable tree species.

1.2 Problem Statement and Justification

According to MNRT (2001), vast areas covered by miombo woodlands occur in the general lands (non-gazetted) estimated to be 54%, and lack proper management which result in unsustainable utilization of these woodlands. The miombo woodlands of Tanzania are degraded due to unsustainable extraction of different products.

Terrestrial ecosystems especially woodlands and forest vegetation have the greatest potential for mitigating atmospheric carbon dioxide emissions through conservation and management (Brown *et al.,* 1996, Munishi and Shear 2004; Munishi *et al*., 2010; Munishi and Shirima 2010). The Miombo woodlands of Tanzania are likely to have high potential for carbon storage and mitigation of carbon dioxide emissions due to its dominance (Munishi *et al.,* 2010). However, like any other countries the miombo woodlands in Tanzania are undergoing the greatest change due to heavy use for woodfuel supply and other uses (Campbell, 2002). Unsustainable continual removal of trees from the woodlands results in carbon emissions and change in the structure and composition of the stands (Chidumayo, 1993).

It is estimated that 2 246 847.2 m^3 of wood are consumed per year in Chunya District for wood fuel and charcoal (URT, 1997). It is anticipated from simple survey that most of the wood are extracted from the nearby Miombo woodlands, in particular Mapogoro forests. However, there is very limited understanding on the status of wood removal and its contribution to CO_2 emissions in Mapogoro woodlands of Chunya. Further, relatively little has been done to assess the effect of forest and woodland degradation on carbon stocks and emissions thereof in Tanzania.

Tanzania being one of the nine pilot countries undertaking REDD+ initiatives is obligated to calculate its forest area, rates of deforestation and degradation, which will act as baseline information of emission levels. Therefore this study aimed at assessing carbon emission from miombo woodland in Chunya district due to degradation. The results will assist in providing useful data on impacts of degradation on carbon stocks and structure of miombo woodland in Tanzania.

1.3 Objectives

1.3.1 Overall objective

To quantify the effects of woodland degradation on stand structure, carbon stocks and subsequent carbon emissions in miombo woodlands.

1.3.2 Specific objectives

The specific objectives

i. Determine the relationship between stump diameter, tree height and diameter at breast height

ii. Determine annual and total wood volume removals from Manga and Mapogoro woodlands.

iii. Determine the effects of woodland degradation on stand structure in Manga and Mapogoro woodlands.

iv. Estimate the amount of carbon lost due to woodland degradation in Manga and Mapogoro woodlands.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Miombo Woodlands in Tanzania

According to Mnangwone (1999) as cited by Isango, (2007), Miombo constitutes the largest single vegetation type in the country (93.2 %). The relatively dry miombo woodlands cover extensive areas of Shinyanga, Kigoma, Tabora, Rukwa, Mbeya and Iringa regions and wet miombo occupies the south- eastern regions namely: Lindi, Mtwara, Songea, Mbeya, Iringa and Morogoro (Millington *et al.*, 1994). Miombo occurs at altitudes from near sea level to about 1600 m, with annual rainfall ranging from 500 mm to 1200 mm (Jeffers and Boaler, 1966).

Miombo woodlands in Tanzania consists of two main layers, the tree canopy and the herb or ground layer, plus an under-wood layer of smaller trees plus the herb or ground layer. In some places a shrub layer also exists (Jeffers and Boaler, 1966; Acres *et al.,* 1984). According to Jeffers and Boaler (1966), the canopy of mature miombo stands in Tanzania reach a height of 10 to 20 m. Although slightly open in some areas, the ground layer is dominated by *Hyperrhenia* sp grasses with saplings of the main canopy species and they are often subject to burning (Jeffers and Boaler, 1966; Lawton, 1982; Tuite and Gardiner, 1990). These woodlands differ in the degree of canopy closure and in species composition (White, 1983). Where canopy cover is complete, the ground layer often includes a large proportion of herbs and grasses and the height reaches 50 cm (Jeffers and Boaler, 1966).

Miombo woodlands in Tanzania and elsewhere in the region are highly depended as source of livelihoods of local inhabitants although uses are believed to be inefficient.

For example, it is estimated that humans use only 10% of the fruits potential and the rest are wasted, due to poor markets and rudimentary processing technologies in the country (Nsubemuki *et al.,* 1997).

2.2 Tree and Shrub Species Diversity in Miombo Woodlands

The knowledge of species diversity is particularly useful in understanding the importance of tree species to people's livelihoods, ecological conservation, and carbon sequestration. Chidumayo *et al.* (1996) reported that, diverse uses of miombo woodlands and the need to optimize the sustainable flow of benefits to communities living in the miombo environment pose a challenge. Species diversity refers to the number of different species in a particular area and their relative frequencies (Wilson, 2006; Harrison *et al.,* 2007). Species richness may be defined as the actual number of different species in a community rather than the number of individuals contained therein (Harrison *et al*., 2007). According to Harrison *et al.* (2007), species evenness as the relative abundance with which each species is represented in a community while composition is the assemblage of plant species that characterize the vegetation (Martin, 1996). The most common measure of species composition is richness (number of different species) and abundance (number of individuals per species found in a given area). Therefore, as species richness and evenness increases, so does the species diversity.

Miombo woodlands are extremely rich in plant species despite of their apparent uniformity in structure and composition over large areas. The number of higher plant species in the miombo ecoregion is estimated to be 8500 species, out of which 334 are trees (Frost, 1996; Rodgers *et al.,* 1996). In another study, Malaisse (1978) reported at least 480 flowering plant species from miombo woodlands of Katanga (Democratic Republic of Congo) while Nduwamungu (1997) documented a total of 99 tree and shrub species in miombo woodlands of Kitulang'alo, Tanzania. Maliondo *et al.* (2005) reported 48 tree species belonging to 16 families in a 40 ha in Handeni District, Tanzania. Dominant tree species in miombo are those in the family Fabaceae, sub-family Caesalpinioideae in the genera *Brachystegia, Julbernadia* and *Isoberlinia*, other species include *Pterocarpus angolensis*, *Parinari curatellifolia*, *Afzelia quanzensis* and *Erythrophloem africanum* (Chidumayo and Frost, 1996). Maliondo *et al.* (2005) reported *that Brachystegia boehemii* and *Julbernardia globlora* were the dominant tree species in the wet miombo of Handeni, while *Combretum amiculatum, Dichloryhynus candylopocarpon, Brachystegia microphylla* and *Pseudolachnostylis maprouneifolia* were also abundant. A number of indices are known for measuring species diversity in communities. A diversity index is a mathematical measure of species diversity in a community. Diversity indices provide information about community composition and take the relative abundances of different species into account (Magurran, 1988).

2.3 The Ecology of Miombo Woodlands

Miombo woodland in general occurs in the sub-humid areas in central Africa on old and nutrient poor soil. The annual rainfall varies from 650-1400 mm (Campbell, 1996). Miombo forest is divided into dry Miombo woodland and wet Miombo woodland (Chidumayo, 1995). The amount of organic matter is low in Miombo woodland soil. Top soil in the dry Miombo has a content of 2% organic matter which decreases with soil depth (Chidumayo, 1994b). The ground cover can contain a thick grass cover or only a spare cover of herbs and grass species. The canopy comprises of woody plants, dominated by umbrella shaped trees (Campbell, 1996). Miombo woodlands, a specific type of savannah characterized by deciduous arborescent species dominated by the genera *Brachystegia* and *Julbernardia* and grasses. The miombo ecoregion is the most extensive vegetation type in Africa south of the equator (Campbell *et al.,* 1996). This miombo woodland ecosystem extends across about 2.8 million km^2 the southern sub-humid tropical zone from Tanzania and Democratic Republic of Congo (DRC) in the north, through Zambia, Malawi and eastern Angola, to Zimbabwe and Mozambique in the south (Desanker *et al.*, 1997). The ecoregion constitute the largest more-or-less contiguous block of deciduous tropical woodlands and dry forests in the world and is a home to over 100 million people and the source of products and services which cover the basic human needs (Bond *et al.,* 2010). Besides local interest, the woodlands also have global significance with respect to environmental and biodiversity conservation. About half of the elephants and rhinos left in Africa are found in miombo ecoregion. Nature and wildlife tourism is one of the main economic sectors in the region, with considerable potential for growth (Byers, 2001). Survival of people in this ecoregion has always depended on natural resources of drawn from ecosystem. Many people may even become more dependent on this natural asset as poverty and human population increase (WWF-SARPO, 2001).

White (1983) divided miombo woodlands into dry and wet. The dry miombo woodlands occur in areas receiving less than 1000 mm rainfall annually. They occur in Zimbabwe, central Tanzania, southern areas of Mozambique, Malawi and Zambia. Their canopy height is less than 15 m and the vegetation are floristically impoverished. The wet miombo woodlands occur in areas receiving more than 1000 mm of rainfall per year and these are found in eastern Angola, northern Zambia, south western Tanzania and central Malawi. Canopy height is usually greater than 15 m reflecting general deeper and moister soils, which create favourable conditions for growth. Besides, the vegetation is floristically rich (Frost, 1996).

2.4 Deforestation and Forest Degradation

Tanzania like many other African countries is experiencing serious degradation and deforestation of its forest and woodland resources (VPO, 2001). Current studies on the Tanzania forest cover have indicated that between 1970 and 1998, Tanzania lost around 10 million ha of forest land to other land uses through uncontrolled clearing of forests and woodlands mainly for agriculture and livestock expansion (MNRT, 2001a and b). Degradation of forests and deforestation is taking place both in Government Forest reserves and in un-reserved general land forests (TFWG, 2009).

FAO (2010) provides a figure of 412 000 ha as the rate of annual forest loss in Tanzania, out of a forest estate of around 35 million hectares. Forest degradation is mostly occurring inside forest reserves, the deforestation is particularly rapid and wide spread outside the reserved forests (TFWG, 2009). Forest degradation is considered as changes that take place in the forests or woodland which negatively affects its structure, function or both and thereby lower the capacity to supply products and or services. Forest degradation is assumed to be indicated by the reduction of the canopy cover and /stocking through logging, fire, windfall or other events, provided that the canopy cover stay at above 10% (Tejaswi, 2007). Deforestation involves the conversion of forested areas to non-forest land use such as rural settlements, urban use or logged area. According to Tejaswi (2007), it involves conversion of forest to another land use (which can prevent the natural regeneration of young trees) or the long-term reduction of tree canopy cover below the 10% threshold. A large part of deforestation is approved by authorities for the purposes of infrastructure development, urban expansion, commercial or small scale agricultural development, clear felling for timber trade, etc. In addition, in many countries there are varying amounts of ungoverned deforestation that is forest clearance carried out for the same kinds of reasons but without official approval (Skutch and Trines, 2008).

Degradation is a major factor in the loss of biomass in the forest and woodlands, and thus results into the decrease of the carbon storage potential of the vegetation (TNFR, 2009). Mature Miombo woodland trees are mainly harvested for charcoal making, however, usually some Miombo tree species regenerate by coppicing and recruitment from stunted saplings (Luoga *et al.,* 2003).

2.5 Agents and Drivers of Woodland Degradation

The dynamics and causes of forest and woodland degradation are multifaceted, complex and vary from one place to another (Kanninen *et al.,* 2007). Agents of degradation are those individuals, corporations, government agencies, or development projects that are involved in deforestation or forest degradation. These include large scale farmers, encroachers, hunters, ranchers or plantation companies. Causes/drivers relates to the reasons why degradation is taking place (Tejaswi, 2007). The causes of forest degradation can usefully be separated into two categories; direct or proximate causes and underlying causes.

2.5.1 Direct causes of woodland deforestation and degradation

Direct causes of woodlands and forest degradation involve factors that are directly linked to the act of clearing or degrading land. According to ONF International (2008) direct causes of deforestation and forest degradation differ significantly across countries, following broader patterns of agricultural and infrastructure expansion, and commercial and domestic demand for wood products. Literature shows that forest and woodland degradation has been mainly attributed to the following activities;

Agricultural activities

Agricultural activities that result in the clearing and conversion of woodlands including the establishment of permanent crop land, shifting cultivation and cattle ranching. However shifting cultivation can be less harmful than any other agricultural activities due to regrowth and secondary forest succession following this type of agricultural use- but under very low rural population densities where long fallows can be maintained (Guariguata and Ostertag, 2001). The direct causes that stimulate the decision to convert forest land include: Favourable environmental conditions (e.g. forest in areas with good drainage and soil fertility are more likely to be converted to agriculture), high prices for agricultural outputs (more profitable production, and thus clearing), low wages (smaller costs of forest clearing, and thus more deforestation), demographic changes (e.g. Population growth and higher rural populations can foster further degradation) (Kanninen *et al.,* 2007).

Wood extraction

Wood extraction is the principal intra-sectoral cause of forest degradation and can also lead to deforestation, either directly or indirectly (UKAID, 2010). Wood is extracted from the forest for timber, pulpwood, woodfuel and charcoal. Uncontrolled or under-regulated timber extraction, whether legal or illegal, often lead to degradation and indirectly, to deforestation. Also, road construction associated with logging frequently leads to deforestation by facilitating immigration and conversion of forests and woodlands to agriculture in areas where property rights are unclear or poorly enforced (Kaimowitz *et al.*, 1998).

Infrastructure extension

Forests and woodlands can also be cleared to construct roads, settlements, public services, pipelines, open-pit mines, hydro-electric dams, and other infrastructure. None of these sources tends to be a large factor in terms of the quantitative area of forest land cleared. But indirectly, road construction and improvement is by far the infrastructure development that contributes most to deforestation (Chomitz *et al.,* 2007). This occurs not through the direct space roads occupy, but through their reduction of transport costs, which in turn, enable productive activities to take place in remote areas. Ecuador is one example where road building has been a prime driver of deforestation (Wunder, 2000).

2.5.2 The underlying causes of woodlands and forest degradation

The second category includes the background societal factors that drive direct causes of degradation in woodlands. During past few decades forest crisis has provoked many international, regional and national preservation initiatives, yet many have had little success. This is generally due to the fact that these strategies were focused on the immediate causes of forest degradation, and neglected the underlying causes which are multiple and interrelated (Kanninen *et al.,* 2007). Underlying causes of degradation in some cases are related to major international economic phenomena, such as macroeconomic strategies which provide a strong incentive for short-term profit-making instead of long-term sustainability. They are deep-rooted in social structures, which result in inequalities of land tenure, discrimination against indigenous peoples, subsistence farmers and poor people in general (UNFCCC, 2012). In other cases they include political factors associated with governance factors such as the lack of participatory democracy, the influence of the military and the exploitation of rural areas by urban elites. Ostrom (1990) cited by Kanninen *et al.* (2007) explained that deforestation and forest degradation can result from the combined effect of forest tenure and institutions as a result of weak governance, which in turn, determine the set of incentives which lead to over exploitation. With respect to tenure, deforestation and degradation can occur as a consequence of poorly defined property rights, including systems that reward deforestation with tenure establishment. Where property rights are ambiguous, overlapping or weak, incentives for investing in long term returns from natural resources are also weak.

2.5.3 Other factors

Cultural factors: Cultural factors, including lack of public concern for woodland conservation and the unwillingness to change historic forest practices such as bush burning may contribute to deforestation. But certain cultural values or norms, such as the establishment of sacred forest areas, can also increase protection from land conversion and degradation (URT, 2010).

Demographic factors: Rising populations and migration to the agricultural frontier increase the labour force available for degradation and deforestation. An increasing population in urban and rural areas also raises demand for food and other land-demanding commodities, thus requiring more land to produce them.

2.6 Degradation and Carbon Loss

The carbon cycle of tropical open woodlands is relatively understudied compared to other biomes. These woodlands are subject to frequent disturbance via fires and land clearance. Such woodland degradation threatens terrestrial carbon stocks but is little monitored or modelled (Chidumayo, 2002; Frost, 1996) as cited by (Williams *et al.,* 2007).

Miombo are widely thought to be undergoing rapid degradation as a result of human activity (Abbot *et al.,* 1999). People live in the vicinity of the woodlands, while some reside inside the woodlands that are in the public domain. They rarely live in the woodlands set aside as the government forest reserves, but do encroach them for several products. Where the woodlands occur outside the forest reserves, clearing for agriculture has taken place over the years (Kowero, 2001). Accurate statistics on the rate and extent of deforestation and woodland degradation of miombo are not available at the ecosystem, regional or national levels (Campbell *et al.,* 2007).

The drivers for woodland degradation vary markedly between the countries in the region depending largely on the location, physical access, topography rates of economic growth, and land tenure. These processes can often reinforce each other and are often aided by the development of mines, urban settlements, or the upgrading of the development of new roads.

Miombo woodlands of Tanzania are likely to have high potential for carbon storage and mitigation of CO_2 emissions although reliable information about the estimate of their potential is inadequate (Munishi *et al.,* 2010). The impact of degradation through wood removal on the carbon storage is even less well known and for most forest types there are no data on the impacts of degradation on carbon storage. However in the Eastern Arc Mountains forest degradation due to wood removal was estimated to reduce carbon storage by 65 million tones from the network of 150 reserves within the ecoregion (Burgess *et al.,* 2010).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

3.1.1 Geographical location

The study was conducted in Mapogoro miombo woodlands in two different forest land tenure named Manga forest reserve and Mapogoro General land in Chunya District, Mbeya, Tanzania. Chunya is located in the north-western part of Mbeya Region (Fig. 1). The district is among the seven districts of Mbeya Region and lies between 7^0 and 9^0 latitudes south of the equator, and between 32^0 and 34^0 longitudes of Greenwich. The district is bordered by Singida and Tabora Regions to the north; Iringa Region and Mbarali Districts to the East; Mbeya Districts to the south while Rukwa region and Lake Rukwa to the West. It is the biggest district in the region occupying a total area of 29 219 000 ha (46% area of Mbeya Region) (URT, 1997). According to URT (1997), Chunya land area is classified into different uses including arable land occupying 3 005 000 ha (78.73%), Game reserves 2 000 000 ha (6.85%), Forest reserves 396 400ha (1.36%), water bodies 1 505 000 ha (3.78%) and the other uses 2 712 600 ha (9.28%).

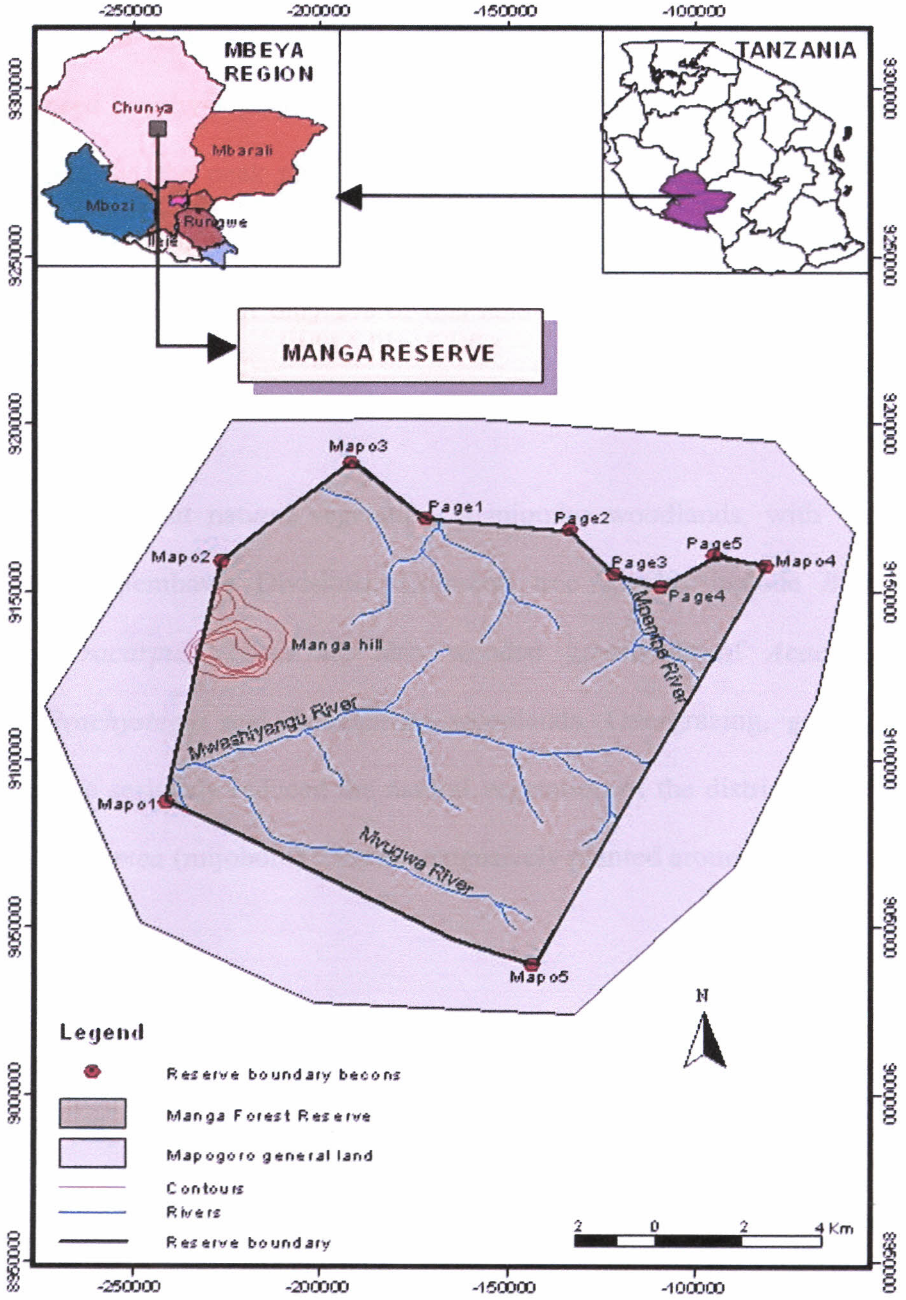

Figure 1: Map of Tanzania and Chunya District showing Manga Forest Reserve and Mapogoro

3.1.2 Climate and vegetation

The district annual temperature ranges between 21^0 C and 23^0 C annually and is very much influenced by physiography and altitude. Annual rainfall ranges from 600 mm to 1000 mm. Usually, the peak period of heavy rains is recorded during the months of December and March almost every year. Despite the fact that about 78% of the total land is arable, it is estimated that only 2% of this land is currently under cultivation (URT, 1997).

The most predominant natural vegetation is miombo woodlands, with vast areas in Kwimba and Kipembawe Divisions. Common tree species include *Branchystigea, Dalbegia, Pteracarpus*. There are also wooded grasslands of *Acacia comiphora* bushlands, *Brachystegia* and *Julbenardia* woodlands. Overgrazing, gold mining and agriculture have seriously reduced the natural vegetation of the district, and exotic trees such as *Senna siamea* (mijohoro) trees are extensively planted around settled areas.

3.1.3 Topography

Chunya district is characterized by a hilly landscape (Stretching from Mbeya hills with a gentle slope mostly covering the Kiwanja division) with thick forests, miombo woodlands, scattered trees, bush and thickets. The district has flat low lands along Lake Rukwa basin; and plateau between Ibagu plains and that of Lake Rukwa and Chunya mountain range. The main permanent drainage system include rivers Songwe, Lupa and Zira all originating from Mbeya hills. On the other hand, 18 non -permanent rivers (seasonal) exist and mostly flow during rainy season. The main sources of those rivers include Chunya mountain range and hills.

3.1.4 Soil

The study area contains shallow stony with low fertility soil. These have deep quartz dominated sands of Albic arenosols with Orthic ferrasols, Ferralic arenosols and Ferralic cambisols. They occur as red sand, pale sand, good for flue-cured tobacco, maize, sorghum, finger millet, sweet potatoes, cassava and groundnuts along with the cattle and beekeeping and gold mining.

3.1.5 Socio-economic activities

The district's major economic activities are farming, animal husbandry, and mining. Other sectors include: fishing and beekeeping. Tobacco is the leading cash crop; other cash crops include, cotton, sorghum and paddy. Despite the existence of abundant arable land and good climatic conditions, the district has no large scale farmers due to poor road network for crop haulage to the market (URT, 1997).

3.2 Data Collection Methods

3.2.1 Sampling design

In order to cover as much as possible of the whole woodland area and variation between vegetation cover, a systematic sampling design was adopted in this study. Systematic sampling design ensured an even spread of the samples throughout the woodland area and thus increased the chances of including all vegetation types in the woodland (De Vries, 1986; Philip, 1994).

3.2.2 Sampling procedures

Data were collected through forest inventory which is a procedure for obtaining information on the quantity and quality of the woodland resources and other characteristics of the land on which the trees and shrubs are growing according to

(Malimbwi, 1997). The data were supplemented by secondary data obtained through literature survey (e.g. research reports, published and unpublished work and internet search).

3.2.3 Sample size, shape and size of the plots

Sample size was determined by using a pilot mean and predetermined standard error Munishi (2005) which was obtained during reconnaissance survey. A total number of 50 plots were laid out in the reserved land and 50 plots in the general land forest. The sampling unit was a rectangular plot with a size of 20m x 40m (0.08ha). The plot was divided into subplots of 10m x 10m and 5m x 5m, this methodology has been used extensively by the North Carolina Vegetation Survey (Goslee, 2006). Rectangular plots are said to be efficient in heterogeneous area compared to circular plots (Stohlgren, 1995).

The following formula was used to determine sample size in each site;

$$n = \frac{s^2}{(x \times 0.1)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (1)$$

Whereby,

S^2=variance of the mean

x=Sample Mean

n=Number of Sampling Units

Source (Munishi, 2005)

3.3 Ecological Data Collection

Data recorded include: species name for all trees, shrubs and stumps measured, counts of regenerants, diameter at breast height (dbh) for all trees and shrubs. Within the 5m × 5m sub plots regenerants were counted while within each of the 10m × 10m sub plots all trees and shrubs with DBH ≥ 5 and stumps were measured; in addition to DBH, three trees (large, medium and small) in each plot were measured for height. Other data which were collected includes the uses of harvested trees and age of stumps. Coordinates of the sampling units were taken using a Geographical Positioning System (GPS).

Stump age was subjectively decided with the help of field assistants based on their personal experience and knowledge of miombo trees and shrubs. There were no records for harvested wood in both the reserve and general land and hence the number of felled trees was recorded from the stumps. Newly harvested stumps – (within the last year) and old harvested stumps (harvested more than a year ago) were recorded. The distinction between the two ages of stumps was established by the color and freshness of the exposed wood, the size of the sprouts/coppices and the presence of fire scorch on exposed wood. In each case the diameter of the stumps was measured, the species identified and the main purpose of the removal established with the aid of local elders well acquainted with ethnobotany and aspect of wood utilization. The criteria used for identification of the harvested species were coppice growth, wood and bark characteristics of the stump. The following criteria was used to identify the purpose of harvesting species, stump height, presence of fire scorch, proximity to charcoal kiln or sawing platform to the stump. Tree and shrub species were locally named by local botanist; botanical identification was made by matching local names with botanical names available in the literature.

3.4 Data Analysis

Analysis of inventory data to examine the structure of the stand, involved computation of such characteristics as stem density (SPH), basal area (G) and standing volume (V). All variables assessed for standing crop were similarly done for cut trees as to quantify harvests. The analysis was summarized using Microsoft Excel spread sheet and statistical analysis was done by R statistical package. Before computation of various variables, checklists of trees and shrubs was developed. Botanical names were matched with local names in the checklist. Each tree was then given a code number for subsequent analysis.

3.4.1 Stocking parameters

For the purpose of this study stocking parameters included: stem density (N) (trees and shrubs and cut-wood), basal area (G) (trees and shrubs; and cut-wood) and volume (V) for standing crop (trees, shrubs and cut- wood).

Density (Number of stems/ha)

Stem density was determined as;

$$N = \frac{1}{n}\sum \frac{n_i}{a} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Where:

n_i = number of trees counted

n=number of plots

a=plot area in ha.

Basal area

Stand basal area is the sum per hectare of cross sectional areas of all trees estimated at breast height (Malimbwi, 1997). Therefore mean basal area (m^2 ha^{-1}) was calculated from measured stem diameters at breast height (1.3m) for all woody individuals in all plots.

$$G = \sum \frac{G_i}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (iii)$$

This can be explained mathematically as follows;

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

Gi= basal area of the i^{th} plot (m^2ha^{-1}),

n= number of sample plots

Volume

The total tree volume was calculated by using the following formula developed by Malimbwi *et al.* (1994) for Miombo woodlands.

$$V = 0.0001 d_i^{2.032} \times h_i^{0.66} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(iv)$$

Where V=volume in m^3,

d=Diameter at breast height in cm,

h=Height of a tree in m.

Tree heights were estimated using the model which was fitted by using sample trees and shrubs for this study.

$$ht = 5 + 0.27(dbh) \qquad R^2 = 0.62, p < 0.0001 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(v)$$

Diameter at breast height of cut-wood was estimated from the measured diameter of stumps (basal diameter). Model (i) was used to estimate DBH of cut-wood which was developed by using DBH – basal diameter relationship.

$$dbh = -1.77 + 0.924(bd) \quad R^2 = 0.9628, p < 0.0001 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(vi)$$

3.4.2 Above ground carbon and estimation of emission from woodland degradation

Biomass of the standing and removed trees were calculated by multiplying volume with average wood basic density where species specific or genus/family value were used (Munishi and Shear 2004). Tree carbon was then obtained through multiplying the tree biomass by 0.49 (Munishi and Shear, 2004, Munishi *et al.,* 2010). A factor of 3.67 tCo_2 per unit of C was used to convert obtained carbon to emissions according to (IPCCC, 2003).

3.4.3 Statistical analysis

Relationship between tree parameters

Sampled 300 trees were used for models making and validation. A total of 180 trees were used in developing and the remaining 120 were used for validation. Regression analysis was conducted using R software whereby height was both regressed against DBH and stump diameter separately, and DBH was regressed with stump diameter (BD). Stand and harvested parameters from the reserve and general land were compared using t test in R software.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Models Relating Different Tree Parameters

Relationship between tree height and stump diameter, tree height and diameter at breast height and diameter at breast height and stump diameter were developed using 180 standing trees comprising different species. Height was both regressed against DBH and stump diameter separately, and DBH was regressed with stump diameter (BD). The following models were obtained;

$$dbh = -1.77 + 0.924(bd) \quad R^2 = 0.9628, p < 0.0001 \ldots\ldots\ldots\ldots\ldots\ldots..(vii)$$

$$ht = 4.325 + 0.257(bd) \quad R^2 = 0.64, p < 0.0001 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(viii)$$

$$ht = 5 + 0.27(dbh) \quad R^2 = 0.62, p < 0.0001 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(ix)$$

Where

dbh= Diameter at breast height,

bd = stump diameter,

Ht= Tree height

The model for estimating DBH from BD and height from BD and DBH and height were all significant, and similar methods was used by Mafupa (2006) and (Luoga, 2001).

4.2 The Forest Structure

4.2.1 Stem density (SPH)

The stem density (SPH) in Manga Forest Reserve and general land was 207 ± 12 and 213 ± 16, stems ha^{-1} respectively for trees and shrubs. The distribution of SPH in both general land and forest reserve followed the expected reversed J shape (Figure 2). This is an indication of active regeneration and recruitment (Phillip, 1983). Accordingly, active regeneration and recruitment in Miombo woodlands in this study is a good sign of sustainability of the woodland stock.

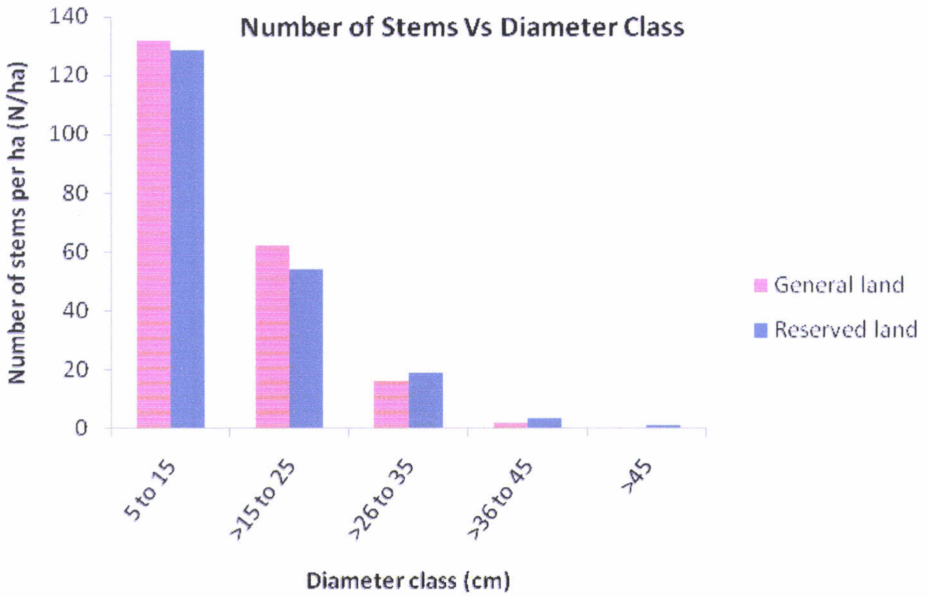

Figure 2: Diameter class distribution of trees in Manga Forest Reserve and General Land

However the observed stem density is lower than those reported elsewhere in miombo woodlands. The number of stumps reported in this study (Table 2) indicate removal intensity from the woodland for various reasons which could be the reasons for less number of stems observed in these forests. Malaisse (1978) reported 520 – 645 stems per hectare in miombo woodlands of Katanga (DRC), Rees (1974) and Chidumayo (1993) recorded SPH of 762 and 750 respectively in wet miombo woodlands of Zambia while Nduwamungu and Malimbwi (1997), Mafupa, (2006) reported SPH of 691 and 722 in coastal miombo woodlands of Kitulang'alo and Igombe, Tanzania respectively.

Table 1: Harvesting Intensity (Wood and carbon Removals) in Mapogoro Woodlands, Chunya District Tanzania

Woodland type	Stump age	SPH	G ($m^2 ha^{-1}$)	V (m^3 ha^{-1})	Biomass (t ha^{-1})	Carbon (t ha^{-1})
Manga Reserve	New	107 ± 8	0.98 ± 5.1	6.63 ± 3.0	4.37 ± 0.2	2.14 ± 0.2
	Old	80 ± 6	0.55 ± 3.4	3.9 ± 2.0	2.57 ± 0.2	1.26 ± 0.1
Total		187 ± 9	1.53 ± 5.06	10.53 ± 3.1	6.95 ± 0.3	3.40± 0.90
Mapogoro general land	New	141 ± 6.7	1.08 ± 3.74	8.2 ± 2.2	5.43± 0.2	2.66 ± 0.1
	Old	84 ± 7.4	0.5 ± 2.76	3.8 ±1.7	2.54 ± 0.2	1.25± 0.1
Total		216 ± 8	1.7 ± 4.73	12 ± 2.3	7.98 ± 0.2	3.91± 0.1

The low number of stems in the study areas could be explained by tree harvesting, mainly for charcoal making and other socioeconomic activities (Table 2 and 4). The density of regenerants was 2168 ± 472 SPH and 832 ± 189 SPH in general land and forest reserve, respectively. Most of the regenerations come from coppicing stumps. This result suggests that there is more recruitment in general land compared to reserved forest. This could probably be explained by the presence of higher number of stumps in the general land which suggesting more harvesting compared to the reserved forest.

4.2.2 Basal area (G)

Figure 3 shows the standing basal area for both the Forest Reserve and General Land. The study depicted mean standing basal area of 5.0 ± 0.3 m^2 ha^{-1} and 4.4 ± 2.9 m^2ha^{-1}in forest reserve and general land, respectively. There was no significant difference between the basal area in the forest reserve and the general land (Table 2). In most miombo woodlands, the basal area range from 7 to 25 m^2 ha^{-1} (Strang, 1974; Chidumayo, 1987; Lowore *et al.*, 1994; Nduwamungu and Malimbwi, 1997; Zahabu, 2001; Mafupa, 2006; Mohamed, 2006; Maliondo *et al.*, 2005). The lower basal area in relation to miombo ecoregion reported in this study can be explained by high exploitation of wood from both forests. Comparisons between diameter size class and basal area show that there is high basal area (m^2 ha^{-1}) in diameter class 15-25 for both forests (Fig. 3).

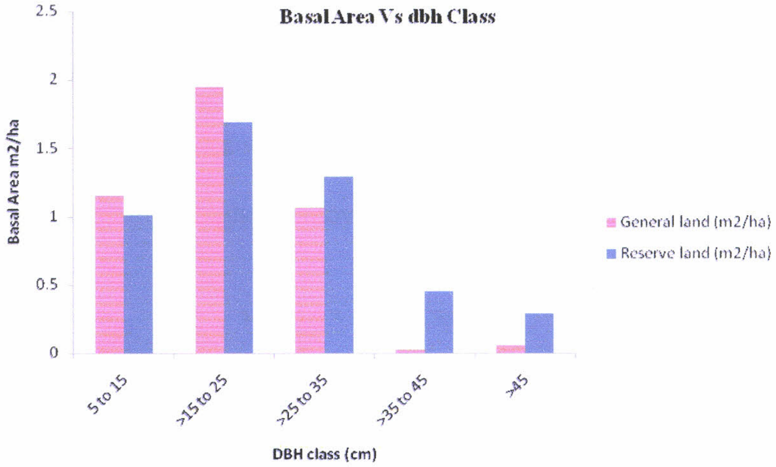

Figure 3: Basal area distribution by diameter classes in Manga Reserve and Mapogoro General Land

4.2.3 Volume (V) of Standing Crop

The mean standing volume was 33±2.3 m^3ha^{-1} and 29±1.63 m^3ha^{-1} in the reserve and general land, respectively. The mean standing volume in miombo woodlands has been reported to range between 14 m^3ha^{-1} in dry miombo woodlands of Malawi (Lowore *et al.*, 1994) and 117 m^3ha^{-1} in Zambian wet miombo woodlands (Chidumayo, 1988). Nduwamungu (1997) and Zahabu (2001) reported mean standing volume of 71 m^3ha^{-1} and 78.8 m^3 ha^{-1} in dry coastal miombo of Kitulang'alo forest reserve, Morogoro, Tanzania while Mafupa (2006) recorded mean standing volume of 87.14m^3ha^{-1}in undisturbed strata and 21.09m^3ha^{-1}in disturbed strata in wet miombo of Igombe Forest Reserve in Tabora, Tanzania. The volumes from this study lie within the range of miombo ecoregion. The difference in mean standing volume in reserve and general land was not significant ($p=0.05$). These results suggest that, although the miombo woodland portrayed a reasonably good regeneration potential (Fig. 2), it is not well stocked.

Similar to basal area, the mean standing volume did not show a normal reversed "J" shape, which is common for natural forests (Fig. 4). The forest reserve had more volume within >15 – 35 cm dbh classes while in the general land most of the volume was >5 - 25 cm dbh classes, indicating a higher removal of trees in the dbh classes >25 cm.

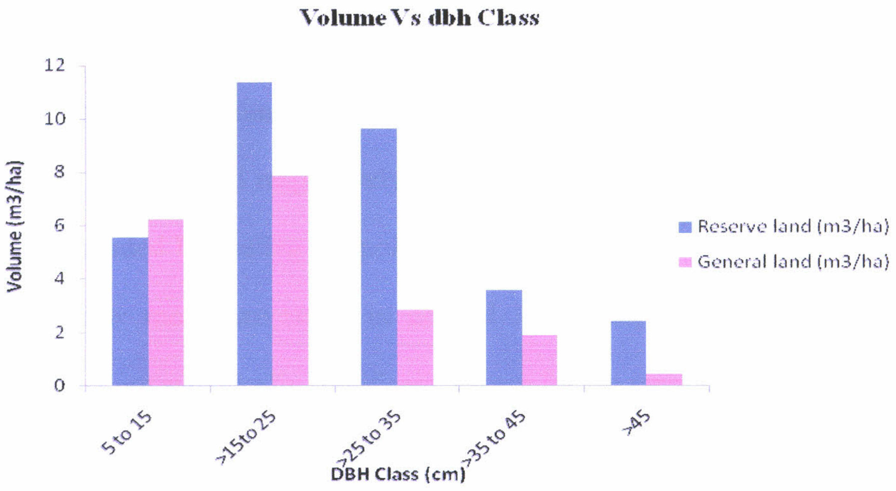

Figure 4: Volume Distribution Diameter Classes in Manga Forest Reserve and Mapogoro General Land

4.3 Harvested and Standing Wood Stock

Tree removals represented a basal area of 1.53 ± 5.06 m^2 ha^{-1}in the forest reserve compared with 1.7±4.73 m^2ha^{-1}in the general land. The volume of newly felled trees was 6.63 ± 3.0m^3ha^{-1} in the forest reserve compared with 8.2 ± 2.2 m^3/ha in general lands. Although the utilization (the total number of old and new stumps, basal area and volume) in public lands was higher than in the reserve, the reserve was not being effectively managed as illegal harvesting was occurring. Table 1 and 3 shows standing (available stock) and harvesting intensity in the study area. The estimated annual wood removal for all uses in both forest reserve and general land exceed by far the reported mean annual increment (MAI) of miombo woodlands which is estimated to be 1.88-4.35$m^3ha^{-1}year^{-1}$, (Ek, 1994 in Malimbwi *et al.*, 2005). Thus the patterns of harvesting are changing the structure and composition of the vegetation substantially.

The results reveal higher number of new stumps compared to old stumps; the main reason for this is that the villagers have been uprooting stumps in past harvested areas for maize cultivation. Charcoal alone contributed 83% of the total wood harvesting in public lands and 88.3% in the reserve; timber harvesting contributes 9.2% and 16.7% of total harvest in reserve and general land respectively (Table 5). Other activities which contributed to degradation included harvesting for poles and ropes and explosive extraction (Table 5). The results show more harvesting in general land compared to the reserve but the differences were not statistically significant, except for the number of stumps (Table 2).

Table 2: Comparison of harvesting intensity (wood removals) between Forest Reserve and Mapogoro Woodlands, Chunya District Tanzania using t-test

	Variable	**Forest Type**		**P value**	**t statistic**
		Reserve	General land		
Harvested	V (m^3ha^{-1})	10.53	12	0.29	-0.57
	New V (m^3ha^{-1})	6.63	8.2	0.23	-0.76
	Old V(m^3ha^{-1})	3.9	3.8	0.3	-0.54
	Biomass (t ha^{-1})	6.95	7.98	0.34	-0.42
	New B (t ha^{-1})	4.37	5.43	0.7	0.38
	Old B (t ha^{-1})	2.57	2.54	0.4	-0.83
	Carbon (t ha^{-1})	3.4	3.91	0.79	0.38
	New C (t ha^{-1})	2.14	2.66	0.7	0.38
	Old C (t ha^{-1})	1.26	1.25	0.4	-0.84
	Stumps (N ha^{-1})	187	216	0.03	-1.96
	New (N ha^{-1})	107	141	0.01	2.4
	Old (N ha^{-1})	80	84	0.8	0..2

Table 3: Stand characteristics in Mapogoro Woodlands

Parameters	Reserve	General Land
Basal Area	4.73 ±0.5	4.4 ± 0.4
Stem density (stems ha^{-1})	232.3±13	283±16
Standing V (m^3 ha^{-1})	32.6±2.3	29.1±1.6
AGB (t ha^{-1})	21.7±1.6	18.6±1.3
AGC (t ha^{-1})	10.6±1.3	9.1±0.9

The total volume of harvested wood ("new" and "old" stumps) was 10.53 ± 3.1 m^3ha^{-1} and 12.6 ± 3.1 m^3ha^{-1} which represents a removal/standing (R/S) stock ratio of (0.3) and (0.4) in forest reserve and general land, respectively. These results show a slightly higher intensity of harvesting in the reserved forest. Luoga *et al.* (2002), reported harvested volume of 7.1 ± 1.2m^3 ha^{-1} in forest reserve and 19.6 ± 2.6m^3ha^{-1} in public lands of Kitulang'alo forest. More harvesting in Mapogoro general land can be explained by the fact that general lands lack proper management and thus give access people for extraction of forest products. This study showed that *Brachystegia spiciformis, Pterocarpus angolensis* and *Brachystegia bohemii* were the most removed trees both in general and Reserved forest. However, though higher biomass, volume and basal area were recorded in the reserve there was no significant difference between the sites (Table 4).

Table 4: Comparison of standing parameters between a Forest Reserve and General Land in a Miombo Ecosystems at Mapogoro Chunya Tanzania using t-test

	Variable	Forest Type		P value	t statistic
		Reserve	General land		
Standing	V (m^3ha^{-1})	32.64	29.06	0.24	0.71
	G (m^2ha^{-1})	4.75	4.46	0.41	0.34
	Biomass (tha^{-1})	21.66	18.63	0.20	0.86
	Stocking (Stems ha^{-1})	232.25	282.91	0.08	-1.39

4.4 Above Ground Carbon and Emissions from Degradation

Miombo woodlands like any other forest type has spatial carbon storage variability due to variation in growth conditions and possibly species composition (Shirima, 2009; Munishi *et al.,* 2010). The mean value of carbon in this study was 10.6±1.3t C ha^{-1} and 9.1±0.9 t C ha^{-1} in Forest Reserve and General land, respectively. *Brachystegia* spp and *Pterocarpus angolensis* accounted for highest percentage of biomass and carbon removals in both woodlands suggesting timber harvesting.

Table 5 shows a list of activities performed by the surrounding communities which resulted into woodland degradation including charcoal, timber and poles extractions contributing to loss of 3.4± 0.9 t Cha^{-1} and 3.93 ± 0.1 t Cha^{-1} (equivalent to 12.5 and 14.3 tCo$_2$e ha^{-1}) equivalent per ha). New harvesting represented loss of 7.85 and 9.76tCO$_2$ e ha^{-1} in the reserve and general land, respectively. These results differ from studies done by other scholars in miombo woodlands. Zahabu (2008) recorded a biomass loss of 1 and 3.5 tons ha-$^{-1}$year^{-1} equivalent to CO$_2$ emissions of 1.67 and 6.5tonsha^{-1}year^{-1} for the woodland forests at Kitulangalo and the lowland and montane forests of Handei.

Table 5: Uses of harvested wood and their proportional contributions (%) to overall harvesting intensity in Reserved and General Land at Mapogoro Woodlands Chunya

Purposes	**Reserved land**		**Public land**	
	No of Sampled Stumps (Nha^{-1})	% of All Stumps	No of Sampled Stumps (N ha^{-1})	% of All Stumps
Charcoal	165	88.3	184	83
Timber	17	9.2	37	16.7
Poles	3	1.6	0	0
Explosives	0.75	0.1	0	0
Ropes	0.75	0.4	0	0
Unknown	0.25	0.1	0	0
Total	187	100	216	100

CHAPTER FIVE

5.0. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has shown that the levels of harvesting in both forests lands are not only resulting into high rates of carbon dioxide emissions, but also what is harvested is higher than what is recruited, suggesting unsustainable use of woodland resources. The annual wood removal of 39.76±3.0m^{3}ha^{-1}far exceeds the MAI of 4.35m^{3}ha^{-1}. Although there is considerable volume in forests reserve, there is substantial harvesting of key species which have potential for carbon sequestration as they constitute a large part of the Manga and Mapogoro woodland ecosystems, indicating that the reserve is not being effectively managed.

Apparently, there is tremendous capacity for the miombo ecosystem to store carbon and act as carbon sink if properly managed. Efforts to ensure proper management of the miombo ecosystem by putting more emphasis on conservation important species such as *B. spiciformis*, *B. bohemii and P. angolensis* can contribute to considerable carbon sink as well as ensure persistent potential for the miombo woodland to store carbon as sinks rather than emissions sources, thus contributing to the REDD+ process in Tanzania and global initiatives at large.

On the other hand, the miombo ecosystem heavily utilized by the adjacent communities for various purposes, creating high degradation pressure on the ecosystem regardless of the management regime which also indicates poor management of both reserves and the general lands.

Prolonged over utilization of wood does not merely change the diameter distribution and standing biomass of the trees, it also affects the temporal and spatial heterogeneity within the woodland communities.

5.2 Recommendations

In this respect, managing the carbon stocks of these ecosystems require rigorous efforts to reduce human-related degradation. This can partly be achieved by allowing the adjacent communities to harvest wood products from the forest under proper management to obtain some of their socio-economic values and ensure local community participation in the management and conservation of the miombo ecosystem. Stored carbon can as well as serve as a source of revenue from carbon trading and if proper benefit sharing mechanism are put in place, can contribute to poverty reduction among the adjacent local communities.

Further, by sustainably managing the carbon stocks in this ecosystem will contribute to global initiatives in combating global warming. If this is realized it will as well contribute to sustainable forest and woodland management in Tanzania.

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APPENDICES

Appendix 1: Field Inventory Form

Date ...., Transect No........................,

Plot No................................

Plot area ...., (ha), General condition of the plot..

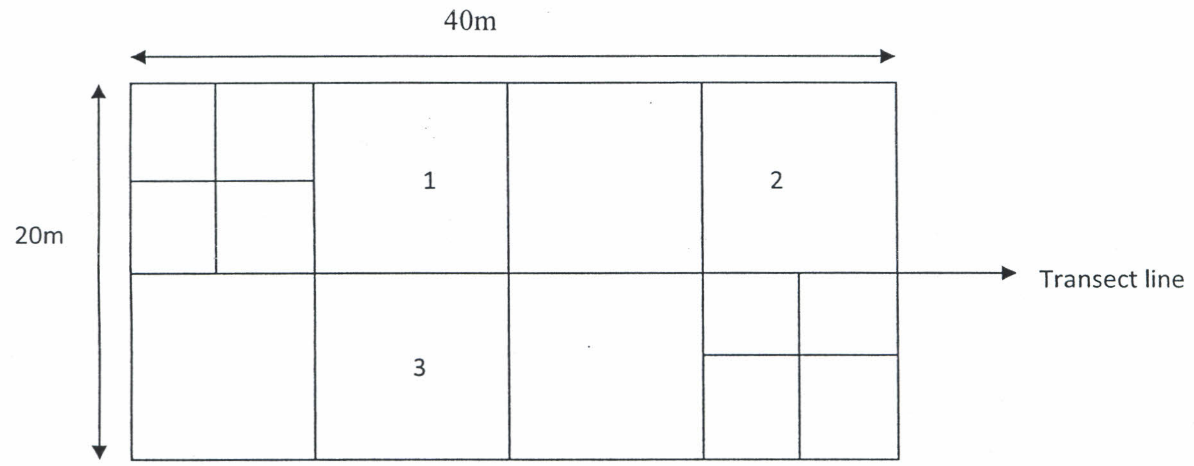
Tree No	Species Name						
	Local Name	Botanical Name	DBH (cm)	SD (cm)	Height (m)	Age of Stump	Utilization

Key: SD= stump diameter, DBH= Diameter at breast height, Ht=Height

Appendix 2: Sample Tree Species for Carbon and Biomass Assessment

Species Code	Scientific Name	General land			Reserve land		
		B	C	%	B	C	%
1	*B. spiciformis*	6.666	3.333	35	7.786	3.893	36.3
3	*P. angolensis*	2.918	1.459	15.3	3.846	1.923	17.9
36	*B. boehmii*	2.158	1.079	11.3	0.824	0.412	3.8
12	*R. natalensis*	1.684	0.842	8.8	1.184	0.592	5.5
5	*L. ovalifolia*	1.142	0.571	6	1.168	0.584	5.4
22	*P. angolensis*	1.068	0.534	5.6	1.308	0.654	6.1
15	*C. molle*	0.64	0.32	3.4	0.71	0.355	3.3
6	*C. grandbractaeta*	0.544	0.272	2.9	0.876	0.438	4.1
10	*P. maprounefolia*	0.454	0.227	2.4	0.868	0.434	4
13	*S. guineese*	0.276	0.138	1.4	0.062	0.031	0.3
4	*V. doniana*	0.238	0.119	1.2	0.46	0.23	2.1
18	*B. bussei*	0.224	0.112	1.2	0.002	0.001	0
9	*B. salifolia*	0.2	0.1	1.1	0.076	0.038	0.4
16	*P. adolfi*	0.192	0.096	1	0.696	0.348	3.2
14	*V. mombassae*	0.172	0.086	0.9	0	0	0
11	*B. africana*	0.136	0.068	0.7	0	0	0
23	*J. globiflora*	0.14	0.07	0.7	0.144	0.072	0.7
20	*X. americana*	0.058	0.029	0.3	0.046	0.023	0.2
17	*L. kirkii*	0.03	0.015	0.2	0.006	0.003	0
2	*A. quanzesis*	0.01	0.005	0.1	0.138	0.069	0.6
7	*S. spinosa*	0.016	0.008	0.1	0.068	0.034	0.3
8	*S. cocculoides*	0.02	0.01	0.1	0.02	0.01	0.1
31	*C. abbreviata*	0.018	0.009	0.1	0	0	0
37	*S. quinqueloba*	0.018	0.009	0.1	0.008	0.004	0
19	*A. xanthophloea*	0.002	0.001	0	0.012	0.006	0.1
21	*V. madagascariensis*	0	0	0	0	0	0
24	*O insignis*	0	0	0	0.864	0.432	4
25	*D. cinera*	0.002	0.001	0	0	0	0
26	*E. divinorum*	0	0	0	0	0	0
27	*P. curatellifolia*	0.002	0.001	0	0.028	0.014	0.1
29	*E. abyssinica*	0	0	0	0.152	0.076	0.7
30	*M. mochisia*	0	0	0	0.042	0.021	0.2
32	*A. garckeana*	0.008	0.004	0	0.056	0.028	0.3
33	*A. senegalensis*	0.006	0.003	0	0.024	0.012	0.1
35	*S. angolense*	0	0	0	0	0	0

Appendix 3: Shape and size of the plot



Appendix 4: Forested Area of Tanzania Mainland

Forest type	Area Km^2	Percentage %
Closed forest	24313.00	6.1
Miombo woodland	374356.00	93.2
Mangroves	1569.00	0.4
Plantations	1349.00	0.3
Total	401587.00	100.00

Source; Mnangwone (1999)