CARBON STORAGE POTENTIAL AND CLIMATE CHANGE MITIGATION: A CASE OF PUGU FOREST RESERVE, KISARAWE DISTRICT, TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN MANAGEMENT OF NATURAL RESOURCES FOR SUSTAINABLE AGRICULTURE OF SOKOINE UNIVERSITY OF AGRICULTURE.

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ABSTRACT

Pugu Forest Reserve is a coastal forest covering an area of 2,410 hectares; but has been significantly altered by on-going extraction and conversion to other land uses which releasing carbon dioxide into the atmosphere thus making the forest a net emitter of the greenhouse gases. Though some empirical data exist regarding carbon storage in African coastal forests, little has been done to assess and quantify the carbon stocks and emissions associated with deforestation and/or degradation in all coastal forests, Pugu Forest Reserve inclusive. This study estimated carbon storage of Pugu FR to quantify the above ground carbon in the tree component, the understory carbon components and carbon storage in the soil. An inventory was conducted using a 20m x 40 m (0.08 ha) plots. Above ground tree carbon was determined using an allometric model that uses trees DBH $\geq$ 5 cm as predictor variable. Carbon storage in litter, herbs and dead wood was determined using Loss of Ignition method, while Walkley-Black method was used to analyse soil carbon. The total carbon density for all 5 pools was 30.95 t C ha^{-1} equivalents to 113.59 t CO_2e ha^{-1}. The mean carbon densities for the above ground components was 6.75 t Cha^{-1} (24.77 t CO_2e ha^{-1}) in which the tree component accounted for 4.5 t C ha^{-1} equivalent to 16.5 t CO_2e ha^{-1} (14.5%); understory components of litter accounted for 0.52 t C ha^{-1} equivalent to 1.9 t CO_2e ha^{-1} (1.7%); dead wood 1.01 t C ha^{-1} equivalent to 3.7 t CO_2e ha^{-1} (3.3%), herbs 0.72 t C ha^{-1} equal to 2.6 t CO_2e ha^{-1} (2.3%) and soil organic carbon stock was 24.2 t C ha^{-1} equivalent to 88.8 t CO_2e ha^{-1} (78.2%). The mean carbon stored in this forest is lower compared to other coastal forests especially in the above ground component indicating an alarming degradation and destruction. Improved management and restoration of degraded parts can greatly increase the C storage potential and emission mitigation by this forest. Using this information as the baseline carbon stocks; can be potential for participation in carbon trading under the current REDD+ initiatives with contribution to alternative livelihoods and sustainable development to adjacent communities.

DECLARATION

I, Beda Goodluck, do hereby declare to the senate of Sokoine University of Agriculture that, this dissertation is a result of 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.

______________________________ ______________________________

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The above declaration is confirmed by,

______________________________ ______________________________

Prof. P. T. K. Munishi **Date**

(Supervisor)

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DEDICATION

I dedicate this thesis to my almighty God for giving me a precious breath and to my family to inspire them the spirit of learning hard as a weapon of survival of the fittest.

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ABBREVIATIONS

C	-	Carbon
CDM	-	Clean Development Mechanism
CEPF	-	Critical Ecosystem Partnership Fund
DBH	-	Diameter at Breast Height
FAO	-	Food and Agriculture Organization of the United Nations
FBD	-	Forest and Beekeeping Division
Fig	-	Figure
GHGs	-	Green House Gasses
GIS	-	Geographic Information System
GPS	-	Global Positioning System
IPCC	-	Intergovernmental Panel on Climate Change
JFM	-	Joint Forest Management
MNRT	-	Ministry of Natural Resources and Tourism (Tanzania)
NIACAS	-	Northern Institute of Applied Climate Science
REDD	-	Reduced Emissions from Deforestation and Forest Degradation
REDD+	-	Reduced Emissions from Deforestation and Forest Degradation and Enhancing Forest carbon stocks
R^2	-	Coefficient of Variation
SOC	-	Soil Organic Carbon
SUA	-	Sokoine University of Agriculture
TCMP	-	Tanzania Coastal Management Programme
t C ha^{-1}	-	Tonnes of Carbon per Hectare

t CO_2e ha^{-1}	-	Tonnes of Carbon Dioxide Emitted per Hectare
UNFCCC	-	United Nations Framework Convention on Climate Change
URT	-	United Republic of Tanzania

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Dry tropical forests are the most widely distributed habitat type in the tropics (Jaramillo *et al*, 2003), covering 42 % of all tropical vegetation (Murphy and Lugo, 1995). Although dry forests typically have lower biomass densities than moist or wet forests, they store a significant amount of biomass carbon because they cover large areas. These ecosystems have become increasingly threatened by human utilization; a greater proportion of dry forests have been degraded or cleared than moist forests (Mooney *et al.*, 1995; Jaramillo *et al.*, 2003).

Land cover change from tropical dry forests and savannas to agricultural and urban areas can result in significant declines in total system carbon storage due to cutting and burning of aboveground biomass, loss of forest litter, herbs and deadwood additions to the soil carbon pool which leads to increased carbon release from soils through tillage or bare land (Detwiler and Hall, 1988; Woomer, 1993; Munishi *et al.*, 2010).

Releases of ecosystem carbon increase the carbon dioxide (CO_2) concentration in the atmosphere, promoting global climate change (Munishi and Shear 2004; Munishi *et al.*, 2010) where the gas causes infra-red radiation to be retained in the atmosphere, so warming the earth's surface and the lower part of the atmosphere (Laggett, 1990). Apart from CO_2, other greenhouses gases include methane, nitrous oxide, water vapour, ozone and chlorofluorocarbons (Mwandosya, 1999). Due to rise in atmospheric CO_2 concentration, and its implication on global climate, the role of terrestrial vegetation, especially tropical forests has received greater attention as means of mitigating carbon emission to the atmosphere (Munishi, 2001; Munishi and Shear 2004; Munishi *et al.*, 2010).

More than 34% of the Tanzanian land area (34 million hectares) is forestland, consisting of different vegetation types ranging from woodlands, coastal forests, mangrove swamps, tropical rain forests and wooded grasslands and savannas woodlands (FAO, 2007). Sound management of these forests can result into sustainable supply of environmental services such as water catchment, scenic beauty, biodiversity, and carbon sequestration (Munishi *et al*., 2002; Munishi and Shear 2004, Munishi *et al*., 2011). Forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural 'brake' on climate change (Holly *et al*., 2007). Forest soils hold about one-third of the carbon stored in Earth's terrestrial ecosystems (NIACS, 2011).

Despite the importance of avoiding deforestation and associated emissions, developing countries have few economic or policy incentives to reduce emissions from land use change (Santilli *et al.*, 2005). Therefore, management initiatives like REDD+ (Reduced Emissions from Deforestation and forest Degradation and enhancing forest carbon stocks) and CDM (Clean Development Mechanism) are essential for reducing dependency on natural forest as a core source of energy in developing countries. REDD+ is a form of payment for environmental services and has the potential of addressing climate change by reducing greenhouse gas emissions, but also provide positive impacts on forest management, conservation of biodiversity and sustainable development, including poverty reduction (Milledge *et al.*, 2007). Therefore, REDD+ can act as a driving factor towards management of forests for carbon emission mitigation and reducing the rise in atmospheric temperature and climate change at large.

The increase CO_2 in the atmosphere is becoming of global and local concern. The amount of CO_2 sequestered in the forests depends on forest type, forest status; dominant tree species and forest stand age (Munishi, 2001; Munishi and Shear, 2004; Gurney, 2008). This therefore requires mapping of carbon distribution in different cover types among others, as a means to establish baseline for REDD+.

1.2 Problem Statement and Justification of the study

1.2.1 Problem statement

Reducing atmospheric carbon emission and concentration through forest management has recently become an important issue in many countries including Tanzania. The carbon stored in the aboveground biomass (trees, dead wood, litter and herbs) and soil is typically the largest pool and the most directly impacted by deforestation and degradation. Thus, soil carbon analysis and above ground forest biomass estimation is the most critical step in quantifying carbon storage and sequestration potential in tropical dry forests. Tanzania is developing strategies to become REDD+ ready and address local and global initiatives in mitigation of carbon emissions through REDD+ initiatives. Among the major steps in this process is to establish baselines or reference levels over which REDD+ benefits can be gauged.

This process calls for quantification of the existing carbon stocks in forest ecosystems which is at initial stages. Though some empirical data exist regarding carbon storage in African coastal forests, little has been done to assess and quantify the carbon stocks and emissions associated with its deforestation and/or degradation in all coastal forests of Tanzania. Pugu Forest Reserve has been under great utilization pressure with potential losses in its carbon stock. However, little has been done to quantify the potential for the forest to store carbon and implications on carbon emissions resulting from its deforestation/degradation.

1.2.2 Justification of the Study

This study provides a reliable baseline carbon stocks and sequestration potential of Pugu Forest Reserve. The information will assist managers, planners and policy makers in determining the REDD+ potential of these forests through its sustainable management.

1.3 Objectives of the Study

1.3.1 Main Objective

The main objective of this study was to determine the carbon storage potential and climate change mitigation by Pugu Forest Reserve.

1.3.2 Specific Objectives

The specific objectives were to:

1. Quantify the above ground carbon in the tree components.
2. Quantify the understory; herbs, litter and deadwood carbon pools.
3. Quantify carbon storage in the soil (soil carbon pool).

1.4 Research Questions

The following research questions were addressed:

1. What is the above ground carbon in the tree components?
2. What is the above ground carbon in understory components which include dead wood, litters and herbs?
3. What is the potential for soil carbon storage?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Forest Ecosystem in Tanzania

Tanzania still has extensive forest[1] cover, most of which is savanna woodland, mangroves and montane forest, though there are scattered patches of lowland forests. Much of this forest has high biodiversity and endemism especially in the southern highlands region and play vital roles in regional hydrology, carbon storage and the global climate and Eastern Arc Mountains (Mongabay, 2012).

2.1.1 Tanzania Coastal Forests

2.1.2 Geographic scope and distribution

Coastal forests of Tanzania according to Burgess and Clarke (2000) definition and site locations are distributed in six regions of Tanzania mainland covering 17 districts and in Zanzibar covering Unguja and Pemba. The Tanzania mainland regions and number of districts in bracket are: Tanga (4), Morogoro (2), Coast (5), Dar es Salaam (2), Lindi (2) and Mtwara (2). The coastal forests cover a total of 333,412 ha of which 263,932 ha are Central Government Forest Reserves (79.2%) and 66,950 ha (20.0%) are under public land. In addition 2,530 ha (0.8%) are under Game Reserves/National Parks (WWF, 2004).

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[1] Forest area is land under natural or planted stands of trees of at least 5 meters in situ, whether productive or not, and excludes tree stands in agricultural production systems (for example, in fruit plantations and agroforestry systems) and trees in urban parks and gardens.

2.2 Degradation of coastal forests

Human destruction of tropical forests is estimated to contribute up to 17% of global carbon dioxide emissions, resulting in accelerated global warming (Achard *et al*., 2004; Gullison *et al.*, 2007; IPCC, 2007; Van der Werf *et al*., 2009). Field experience and various studies have confirmed that unsustainable timber harvesting; charcoal production, pole cutting, and agricultural encroachment are amongst the most damaging factors (Burgess and Muir, 1994; Durand, 2003; CEPF 2003) to the Tanzanian coastal forests. Degradation of coastal forests and deforestation is taking place both in government Forest Reserves and in unreserved forests on public land (URT, 2000; Salehe, 1995, TCMP, 2001). As an example, the area of closed canopy forest in the Eastern Arc Mountains declined by 1% over 10 years, whereas coastal forests declined by 7% and miombo woodland by 13% over the same period (FBD, 2005). Around towns, forests are being heavily affected by charcoal harvesting (Ahrends, 2005; Milledge *et al.,* 2007) which Pugu-Kazimzumbwi FR and Pande Game Reserve provides a good example (Kaale, 2003, MNRT, 2001a).

2.3 Pools of Carbon Storage

2.3.1 Carbon Stock Potential in Above Ground Forest Components

Forests can act as a carbon (C) source or sink, depending on the balance between uptake of carbon through photosynthesis and release of carbon through respiration, decomposition, fires, or removal by harvest activities (Nabuurs *et al.,* 2008). However, various studies show that different ecosystems have different biomass and carbon densities (Munishi *et al.*, 2010). Due to variation of carbon storage by species and forests types field measurement for estimation of biomass and total carbon storage for specific forests ecosystem are essential (Munishi, 2001; Munishi and Shear, 2004).

The amount of carbon stored in a forest stand depends on its age and productivity (Gurney and Raymond, 2008). It has been noted that, the rate of carbon fixation by young regenerating stands are higher compared to the older stands hence young stands are important for future carbon storage potential (Mackey *et al.*, 2008). According to Munishi *et al.*, (2000); Munishi (2001); Munishi and Shear (2004); (Munishi and Shirima, 2009; 2010), the carbon density in different forest types in Tanzania range from 40t ha^{-1} to 550t ha^{-1} depending on forest type and location. Knowledge on the variations in the forest structure is necessary for predicting potential losses and storage of carbon (Merino *et al.*, 2007).

Land cover change from tropical dry forest and savanna to agricultural and urban areas can result in significant declines in total system carbon storage through cutting and burning of aboveground biomass, loss of forest litter, herbs and dead woods additions to the soil carbon pool, and an increase in carbon releases from soils through tillage (Detwiler and Hall, 1988; Woomer, 1993). Releases of ecosystem carbon increase the carbon dioxide (CO2) concentration in the atmosphere, promoting global climate change (Houghton, 1997).

2.3.3 Soils and Carbon Storage Potential

Forest soils hold about one-third of the carbon stored on earth’s terrestrial ecosystems, but we still have much to learn about how management affects carbon accumulation and loss in forest soils. Since maintaining soil carbon storage is important for mitigating climate change, sustaining forest productivity, and protecting water quality, it is vital to understand how practices like forest fertilization, timber harvesting, and prescribed burns affect forest soil carbon storage. These practices are valuable tools in the acquisition and protection of the natural resources that forests provide, and the ever-increasing human need for forest resources demands a sound scientific basis to management (NIACS, 2011).

The carbon sink capacity of the world's agricultural and degraded soils is 50 to 66% of the historic carbon loss of 42 to 78 gigatons of carbon (Lal, 2004). The rate of soil organic carbon sequestration with adoption of recommended technologies depends on soil texture and structure, rainfall, temperature, farming system, and soil management (Lal, 2004). Strategies to increase the soil carbon pool include soil restoration and woodland regeneration, no-till farming, cover crops, nutrient management, manure and sludge application, improved grazing, water conservation and harvesting, efficient irrigation, agroforestry practices, and growing energy crops on spare lands. Carbon sequestration has the potential to offset fossil fuel emissions by 0.4 to 1.2 gigatons of carbon per year, or 5 to 15% of the global fossil-fuel emission (Lal, 2004).

2.3.4 REDD+ pilot projects in Tanzania towards climate change mitigation

Increasing incidence of global warming due to high concentrations of greenhouse gases has finally made the international community realize that the atmosphere is a finite global common and actions of each individual affects everyone else. National governments and civil society groups have been looking for ways to maintain this common resource by reducing atmospheric concentration of GHGs (IPCC, 1992). One strategy in this regard is carbon sequestration through forestry management activities under REDD. Tanzania has the potential to design and execute a REDD strategy and other related activities (Mwakalobo *et al.,* 2011). It is currently benefiting from donor funding that helped to establish REDD+ actions in the country i.e. there are nine (9) REDD+ projects in Tanzania (Holloway, 2009).

Forests can help mitigate global warming by serving as effective sinks that absorb excess carbon dioxide (CO_2). Forest carbon trading is possible through various market mechanism and projects that help countries around the world including Tanzania to become ready to enter the official and voluntary carbon emission trading systems, reverse deforestation and degradation, and conserve and enhance forest carbon storage.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of Study Area

Pugu Forest Reserve is a coastal forest covering an area of 2,410 hectares and situated about 20 km south west of Dar es Salaam; it is found between longitude 39^0 03’ and 39^0 07’ E and latitude 6^0 52’ and 6^0 56’ S. The forest was gazzeted in 1947 for protection purposes including water catchment/supply and biodiversity conservation. During its declaration as a Forest Reserve, the area used to be covered by a closed forest dominated by *Markamia zanzibarica* whose local name is Mpugupugu hence the name Pugu. Another important dominant tree species is *Diospyros verrucosa* locally known as Mnaki hence the present name of Minaki village/Secondary school. Adjacent villages to Pugu Forest Reserve are Pugu Station, Pugu Kajiungeni and Buyuni.

3.2 Climate

The area is characterized by sub-humid climate for the most part of the year. The average temperature is 27^{o}C. It is cool, dry, and often windy from May to October. The coolest months are June and July, when the temperature is as low as 16 ^{o}C. The annual rainfall is between 900 mm and 1000 mm per year (URT, 1995).

3.3 Sampling design and Sample size

3.3.1 Reconnaissance survey

A reconnaissance survey was carried out to collect information on forest condition, status and determine sample size to be used in a major inventory using a pilot sample. The actual forest inventory work was preceded by determining the actual area of the forest reserve, establishing transect lines and laying out sample plots on a map.

3.3.2 Sampling design

In order to cover the whole area, a systematic sampling design was adopted, in which the first plot was laid randomly and the others followed systematically in an interval of 0.5 km. The forest was divided into 6 transect lines located at an interval of 0.5 km apart from the starting point. A sampling intensity of 0.08 equivalent to 24 rectangular sampling units measuring 20 m x 40 m (0.08ha) (Goslee, 2006) were established systematically in the reserve (Fig. 2), to cover as much variation as possible. The number of sample plots was estimated using the following formula:-

N = (TA x Si) / (Ps x 100)

Where N = number of sample plots,

TA =Total area of the forest,

Si = Sampling intensity and

Ps = Plot size

3.3.3 Size and shape of sample plots

Forest carbon measurements were carried out in rectangular plots of 20m by 40m (Fig.1) and eight sub plots of 10m x 10m were established within each plot. Within the centre line, in two plots of 10m by 10m, three sub plots of 2m x 2m were established and in each 1m^2 sampling for leaf litter, herbs, dead wood and soil was done.

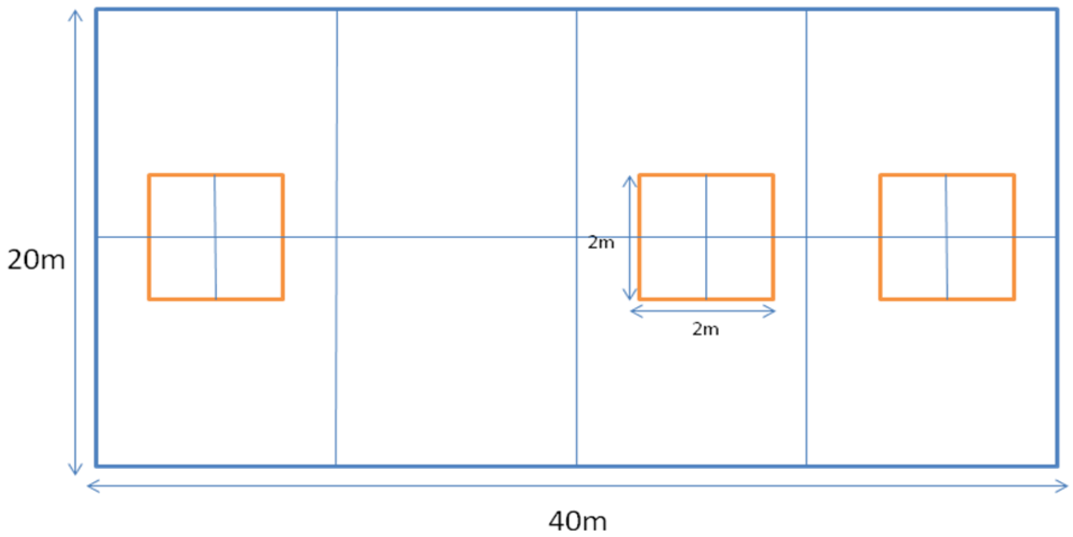

Figure 1: **Size and shape of sample plot**

3.3.4 Plots distribution and layout for inventory of carbon stocks.

A base map (see Fig. 2) was used to produce locations of random sample plots. Plots were laid out and distributed randomly within each stratum using standard sampling method. Coordinates of each plot were also generated for plots tracking during forest inventory.

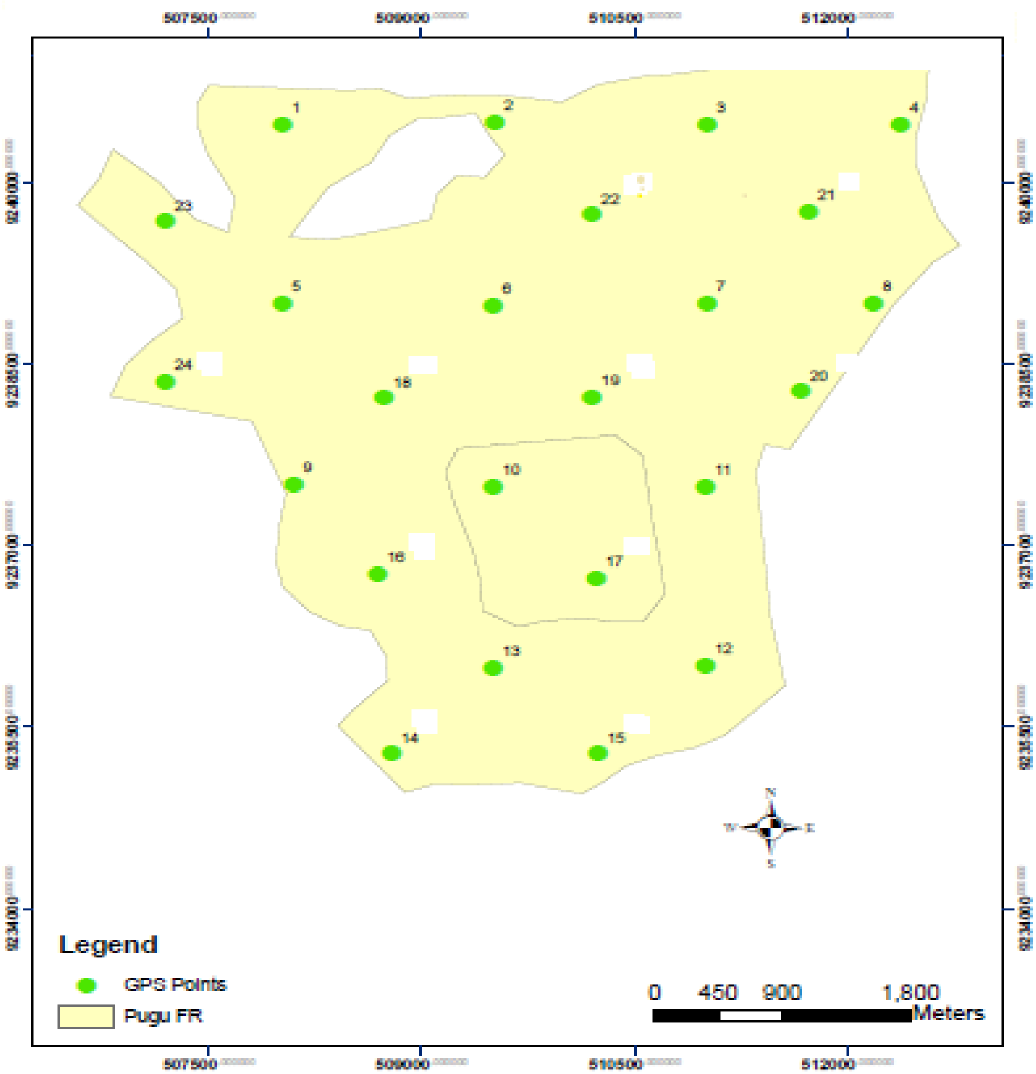

Figure 2: Plots Distribution and Layout in the Pugu Forest Reserve in Tanzania

3.4 Data Collected from the plots

3.4.1 Carbon pools measured

Above-ground tree carbon, leaf litter, herbs, and dead woods and soil organic carbon components were measured for quantification of carbon storage.

3.4.1.1 Above-ground tree carbon

Using a standard method in each of the 20m x 40 m plot, the diameter at breast height (dbh) of all trees $\geq$ 5cm were measured at 1.3m above the ground with adjustments for swollen trees bases, injuries, fluting and other deformities using diameter tape. Each tree was identified and recorded individually, together with its local name and for unidentified species in the field, voucher specimens were collected for identification at the National Herbarium in Arusha, Tanzania.

3.4.1.2 Understory: Leaf litter, herbs and dead wood

In each of the 20m x 40 m plot, three (2m x 2m) sub plots were established at three points along the plot centre in each cardinal direction. All the litter (dead leaves), herbs and dead wood were collected independently in each of the $1m^2$ sub-sub plots; weighed and recorded for green sample weight, a sub-samples was brought to the laboratory to determine oven dry weight biomass for carbon calculation.

3.4.1.3 Soil organic carbon (SOC)

Within 20 plots soil samples were collected from each $1m^2$ sub-sub plot at three points along the centre line at three different depths of 0-15 cm, 15-30 cm and 30-60 cm depth. The three samples from each depth were combined and mixed to form a composite sample in order to determine carbon concentration. Soil cores were collected from each third subplot in each plot using bulk density core samplers for determination of soil bulk density. All materials collected in the cores and composite soil samples were placed in sample bags which were labelled appropriately and taken to the laboratory for further analysis. The soil cores were oven dried at 105 ^{0}C for 48 hours to get constant weight for the determination of bulk density. Soil bulk density was computed as the ratio of the soil oven-dry weight to the soil core volume for each sample (Munishi and Shear, 2004).

3.5 Data Analysis

3.5.1 Quantification of the above ground tree carbon

Tree biomass was determined using allometric model developed by Brown *et al.,* (2006) for tropical dry forests. Various authors have used similar models that use DBH as predictor variable to estimate biomass of trees hence carbon in different forest ecosystems (Chamshama *et al.,* 2004; Malimbwi *et al.,* 1994; Munishi *et al.,* 2000, Munishi and Shear, 2004; Munishi *et al.,* 2010). Dbh is the most significant and easily measured predictor variable for biomass estimation in forest ecosystems (Malimbwi *et al.,* 1994; Munishi *et al*., 2000, Munishi and Shear, 2004; Munishi *et al.,* 2010).

The allometric equation developed by Brown (1997) was used to quantify carbon. This equation includes trees from 5 to 40 cm diameter at breast height (dbh) and it has the advantage of requiring only dbh as the predictor variable. It also has R^2 of 89% making it reliable for the estimation of biomass. The equation with $R^2 = 0.89$ was used: $Y = \exp\{-1.996+2.32 \times \text{In}(D)\}$

Where:

Y = biomass per tree in kg

D = tree dbh (cm)

The biomass was then converted to carbon using a biomass-carbon ratio of 0.49 (MacDicken, 1997; Brown, 1997; Munishi and Shear 2004; Munishi *et al.,* 2010, Munishi and Shirima, 2010).

3.5.2 Quantification of understory carbon (dead wood, litter and herbs)

In order to get carbon stored in understory components of the forest, a destructive sampling technique and specifically the loss on ignition (LOI) was a method used for estimating the organic carbon content (Dean, 1974). Sequential loss on ignition followed the method proposed by Heiri *et al.,* (2001), with modification by Bengtsson and Enell, (1986) which takes into account the loss of mass at 105 ^{0}C and the residues after ignition for the calculation of the LOI which use the following formula.

$$\text{LOI (\%)} = \frac{\text{Weight of oven dried (g)} - \text{Weight of sample after ignition (g)} \times 100}{\text{Weight of oven dried sample (g)}}$$

Organic matter (LOI) / 1.724 = Organic carbon (%)

The number (1.724) is known as a conversion factor to convert organic matter into organic carbon based on the assumption that organic matter contains 58% organic carbon (Santisteban *et al.,* 2004).

The understory carbon density were calculated as carbon concentration percentage multiplied by the total oven dry found in each 1m^2 sub-sub plot and then converted per hectare.

3.5.3 Quantification of Carbon Storage in the Soil

Soil carbon within the forest was computed as the product of volume of soil per unit area (1ha). Samples from each of the three depths were composted for each plot, well-mixed and air-dried and then prepared for carbon measurement by removing stones and plant residue through > 2 mm sieve and then grinded. Walkley-Black wet oxidation method (Nelson and Sommers, 1982) was used to determine the percent organic matter for each soil sample. Soil bulk density was computed as the ratio of the soil oven-dry weight to the soil core volume for each sample (Munishi and Shear, 2004).

The soil organic carbon was calculated as (Pearson *et al.*, 2007).

$$SOC = p \times d \times \%OC \text{ .... eq. (x)}$$

Where,

SOC = soil organic carbon per unit area [t ha^{-1}],

p = soil bulk density [g cm^{-3}],

d = the total depth at which the sample was taken [cm], and

%C = carbon concentration [%]

3.5.4 Computations of carbon contents in different pools

Data were analysed by use of Microsoft excel software where all the biomass data obtained from field measurements were expressed on an oven-dry basis, and converted to carbon by multiplying the oven dry matter values by the carbon ratio (MacDicken, 1997). Later the total and mean carbon of all forest components measured was computed per hectare.

CHAPTER FOUR

4. 0 RESULTS

In this chapter results on carbon storage in different carbon pools which includes aboveground tree carbon, soil carbon, litter, herbs and dead wood carbon are presented.

4.1 Forest Carbon Density

Carbon density for the whole forest (Table 1) was 30.95 t C ha^{-1} equivalent to 113.59 t CO_2eha^{-1} in which above ground carbon was 6.75 t C ha^{-1} equivalents to 24.77 t CO_2e ha^{-1} making up 21.8% of the total carbon content of the forest. The tree component accounted for 4.5 t C ha^{-1} equivalent to 16.5 t CO_2e ha^{-1} (14.5%). The understory components of litter accounted for 0.52 t C ha^{-1} equivalent to 1.9 t CO_2e ha^{-1} (1.7%), dead wood 1.01 t C ha^{-1} equivalent to 3.7 t CO_2e ha^{-1} (3.3%) and herbs accounted for 0.72 t C ha^{-1} equivalent to 2.6 t CO_2e ha^{-1} (2.3%). The soil organic carbon stock was 24.2 t C ha^{-1} equivalent to 88.8 t CO_2e ha^{-1} (78.2%).

Table 1: Forest Carbon Density by Different Pools in Pugu

Components	**t Cha^{-1}**	**tCO_2e ha^{-1}**	**Percentage (%)**
Above Ground			
• Tree	4.5	16.5	14.5
• Dead wood	1.01	3.7	3.3
• Litter	0.52	1.9	1.7
• Herbs	0.72	2.6	2.3
Soil Organic Carbon	24.2	88.8	78.2
Total	**30.95**	**113.59**	**100**

4.2 Carbon Storage by Different Tree Species.

Mean carbon density value of the tree component was 4.5 t C ha^{-1} equivalent to 16.5 t CO_2e ha^{-1} in which *Senna siamea* an exotic species planted during restoration of degraded parts of the forest had the highest value of carbon stock of 0.57 t C ha^{-1} equivalent to 2.1 t CO_2e ha^{-1} followed by *Trema orientalis* a pioneer species that might have spread in degraded areas 0.34 t C ha^{-1} equivalent to 1.2 t CO_2e ha^{-1} and *Diospyros verrucosa* was 0.31 t C ha^{-1} equal to 1.1 t CO_2e ha^{-1} . The remaining tree species had less than 0.2 t C ha^{-1} which is presented in (Fig. 3).

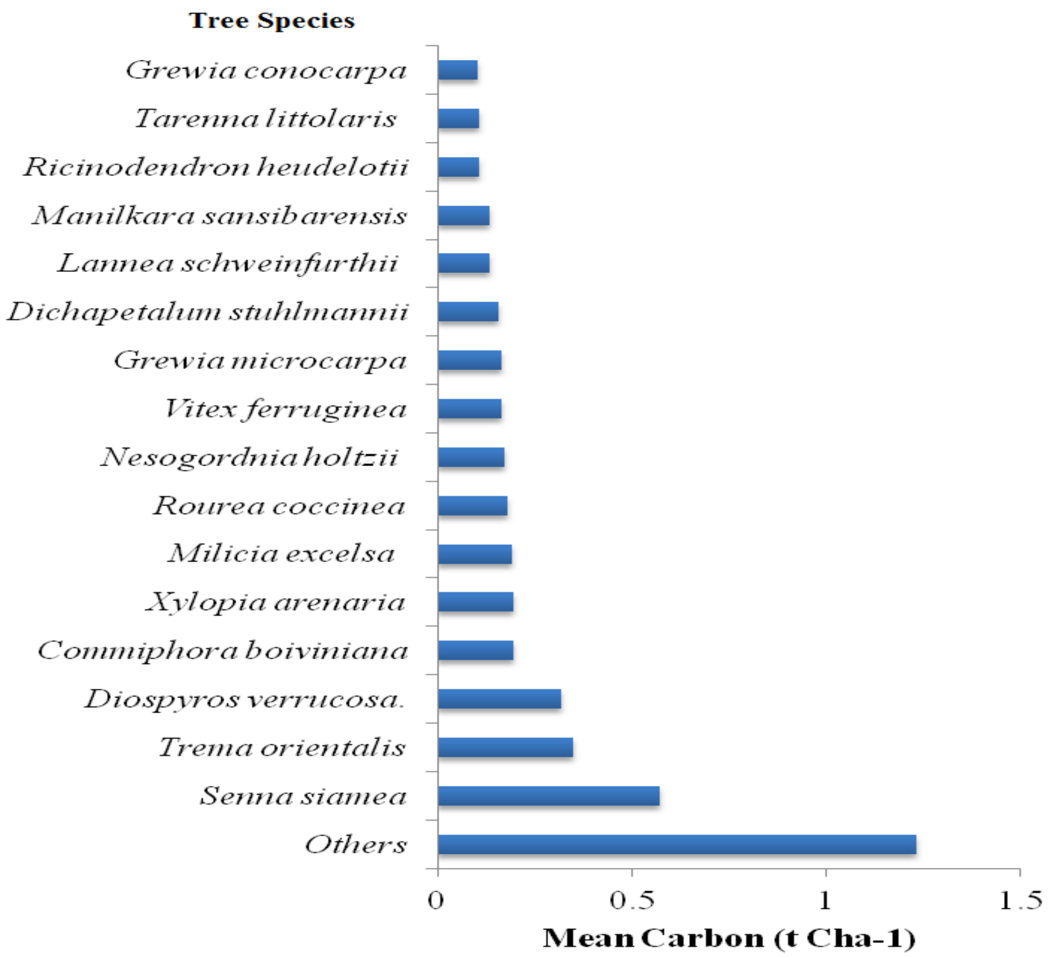

Figure 3: Mean Carbon density of different tree species in Pugu Forest Reserve Kisarawe District Tanzania

4.2.1 Carbon Storage per dbh classes

Different dbh classes had different capacity to store carbon (Table 2). In which the dbh class 5-10 cm contains the most carbon (45.8%) of the total ecosystem carbon followed by 11-15 (20%) and the remaining trees with dbh above 16 cm accounts for the 33.6%. In this case proper management of this forest can easily improve the growth rate and enhance carbon stocks.

Table 2: Carbon storage in different dbh classes of trees in Pugu Forest Reserve

Tree dbh Class (cm)	Mean Carbon (t C ha^{-1})	Percentage (%)
5-10	2.06	45.8
11-15	0.93	20.6
16-20	0.31	6.9
21 (+)	1.2	26.7
Total	**4.5**	**100**

4.2.2 Understory Carbon

The mean understory carbon density of dead wood was 1.01 t C ha^{-1} (Fig. 4) equivalent to 3.7 t CO_2e ha^{-1} followed by litter with 0.52 t C ha^{-1} equivalent to 1.9 t CO_2e ha^{-1} , and herbs with 0.72 t C ha^{-1} equal to 2.6 t CO_2e ha^{-1} respectively.

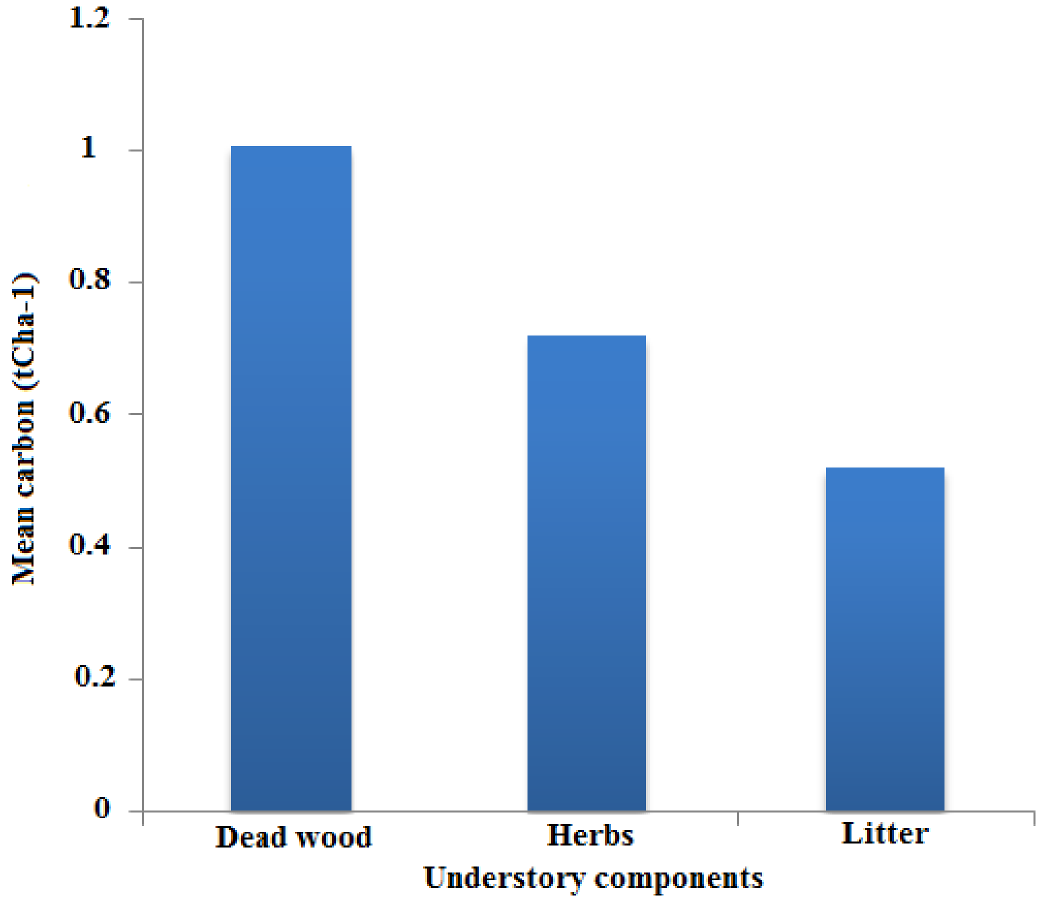

Figure 4: Understory Carbon in Pugu Forest Reserve Tanzania

4.3 Soil Organic Carbon

The total soil organic carbon was 24.2 t Cha^{-1} equivalents to 88.8 t CO_2e ha^{-1}. The average soil organic carbon showed a decrease with depth (Fig. 5). The average values found were 27, 25 and 22 t C ha^{-1} respectively at 0–15, 15–30 and 30–60 centimetres. The result showed decreasing trend with significant differences between the various depths.

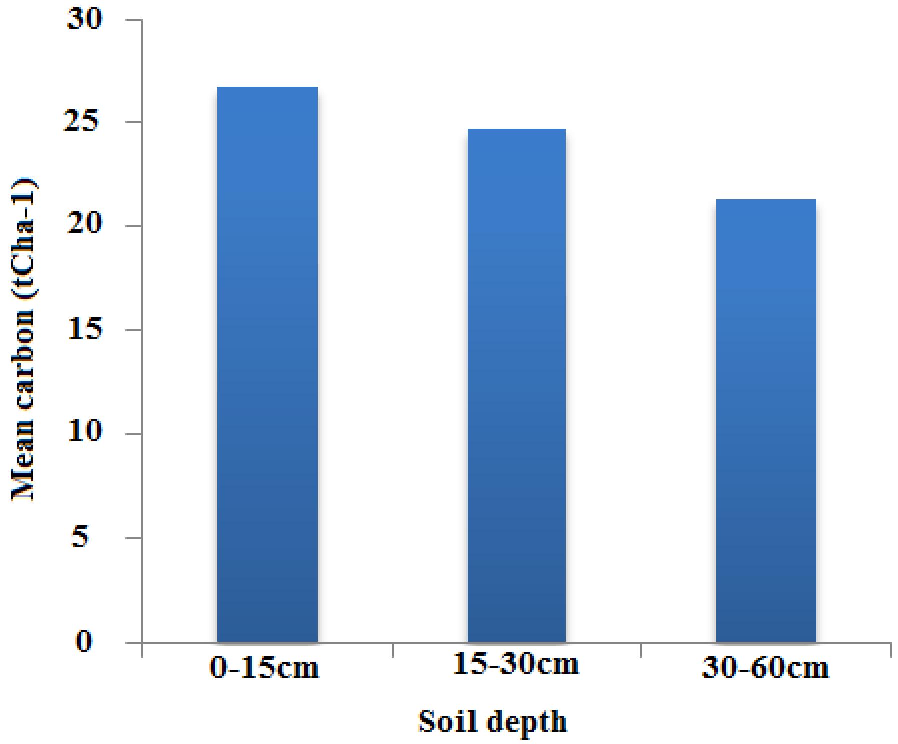

Figure 5: Mean Carbon (t Cha^{-1}) different soil depth in Pugu Forest Reserve Tanzania

4.4 Percentage Contribution to Carbon Stocks by Different Pools in Pugu Forest Reserve

The carbon storage in Pugu Forest Reserve differ from one component to another; in which the below ground component (soil carbon) account for 78.2% of all carbon stored in the forest, followed by the tree component of the above ground pools (14.5%), dead wood (3.3%), herbs (2.3%) and litter (1.7%) as indicated in (Fig. 6).

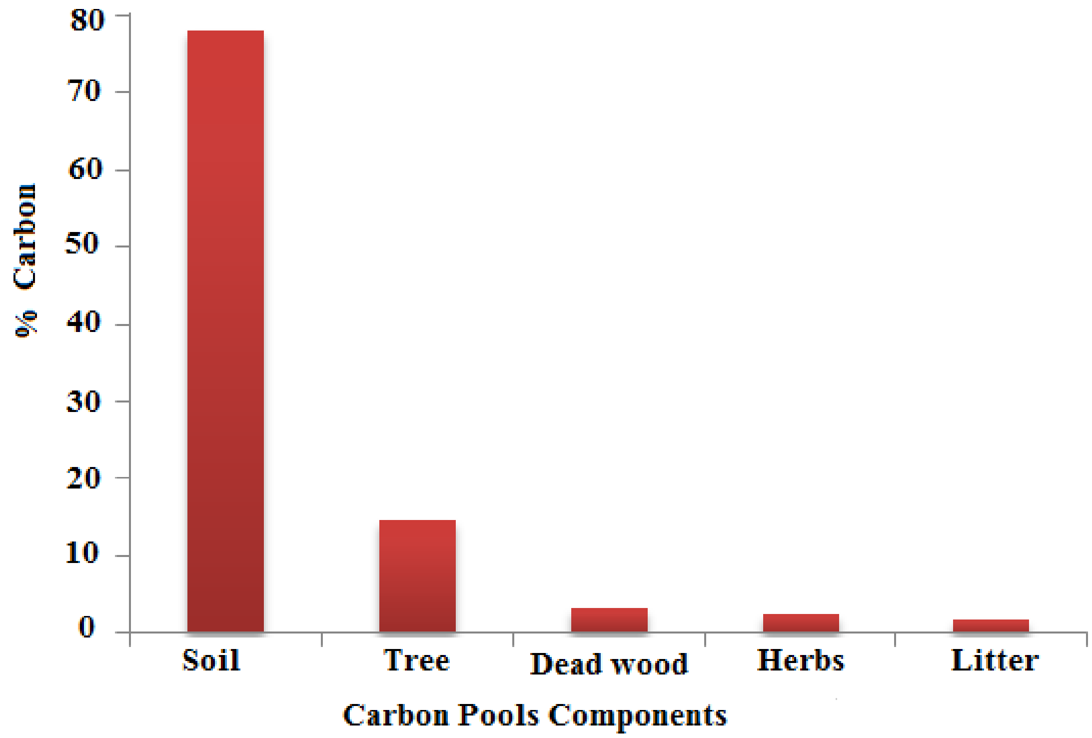

Figure 6: **Percentage of carbon storage per components in Pugu Forest Reserve in Tanzania**

CHAPTER FIVE

5.0 DISCUSSION

Coastal dry forest, like other forest types has special carbon storage variability due to variation in growth condition, elevation and possibly species composition. Carbon density values estimated for Pugu forest fit into the range of estimates for other dry tropical forest. Carbon stocks of vegetation and soil in tropical forests vary greatly by topography, climate and geologic substrate (Vieira *et al*., 2004; Laumonier *et al.*, 2010).

The above ground carbon estimates in Pugu forest of 6.75 t C ha^{-1} was extremely low compared to actual and potential above ground carbon densities in other African dry forests and coastal forests which ranges between 30–46 t C ha^{-1} (Brown and Gaston, 1995; Munishi, 2010). Baccini *et al*., (2008) estimated the carbon density of 64 t C ha^{-1} for the coastal forest in Tanzania. The values obtained in Pugu FR are an indication of extensive deforestation and degradation of the forests with resultant loss in carbon stocks. This amount is also much lower than in many ecosystems in Tanzania. Munishi *et al.*, (2010) estimated the above ground carbon density of the Miombo ecosystem of the Southern Highlands, Tanzania to be 19.2t ha^{-1}.

These differences in carbon densities might be due to varying degree of exposure to human degradation, difference in age of the tree species and the type of woodlands involved. Various studies show that different ecosystems have different biomass and carbon densities. For example, the C density estimates from Afromontane Rain Forests of the Eastern Arc Mountains were found to be between 252 and 581 t C ha^{-1}

(Munishi, 2001; Munishi and Shear, 2004; ECCM, 2007; Munishi and Shirima, 2010). The eastern miombo woodlands in Tanzania have been shown to have C storage potential of between 25 and 80 t ha-1 (ECCM, 2007; Shirima *et al.,* 2010). Pugu Forest carbon stocks were also lower compared to other field studies in dry forests. Owaga *et al*., (1965) estimated an amount of 48 t C ha^{-1} in Thailand, Lambert *et al*., (1980) had an estimate of 39 t C ha^{-1}, in Belize. Martinez- Yrizar *et al.,* (1992) estimated about 22 t C ha^{-1} in Puerto Rico and Jaramillo *et al.,* (2003) estimated 41 t C ha^{-1}; in Mexico

The mean soil carbon densities estimates of 24.2 t C ha^{-1} in all three soil depths were lower than other published values of 45–50 t C ha^{-1} for soils in South African savannas' and Mexican dry forests (Woomer, 1993; Jaramillo *et al.,* 2003). However, this forest soil carbon densities were higher than agricultural soils in Bukoba district, north-west Tanzania adjacent areas 6–18 Mg t C ha^{-1}; (Kattarkandi *et al* 2010) indicating carbon losses on cultivation. The Pugu forest soil estimates were higher than the Zimbabwean miombo woodland soils which accounts for 21 t C ha^{-1} (Woomer, 1993) and lower than soil carbon storage in Afromontane rain forest in Eastrn Arc Mountains of Tanzania with 295 - 418 t C ha^{-1} (Munishi and Shear, 2004, Munishi and Shirima, 2010).

The C storage in the soil component of (78.2 %) is higher than the above ground biomass carbon of 17.7%. Munishi *et al.,* (2000) found higher C pools in the soil than the above ground vegetation for tropical rain forest in northern Tanzania. On the other hand soil carbon pools in the Eastern Arc Afromontane forests have been observed to be slightly lower than the above ground biomass carbon pools (Munishi and Shear, 2004). The difference is likely due to the depth of the soil studied; the other studies were based on soil analysis down to 100cm depth as opposed to 60 cm in this study. Although soil organic C is normally concentrated in the top 30 cm, there can be substantial amounts down to 200 cm resulting from dead roots especially in montane forests where roots may grow deeper than 30 cm (Wojick, 1999).

The greater variation in carbon densities by components in this study clearly show the potential to increase terrestrial carbon storage within protected areas by preventing further forest degradation and promoting restoration of the Pugu forest area. Although the observed carbon densities fell into an expected range of values, it is suggestive that past and on-going disturbances have reduced carbon stocks below the potential of the forest.

Evidence of fuel-wood cutting and charcoal making clearly correlate with the lower carbon densities, with the slow growing nature of dry forest hardwoods and the growing population around the forest, it was possible the cutting of small trees exceed recruitment rate. Felling of medium to large trees more clearly reduced forest carbon stocks. Human destruction of tropical forests is estimated to contribute up to 17% of global carbon dioxide emissions, resulting in accelerated global warming (Munishi *et al.,* 2010). The Plate 1 below shows the extent of harvesting and forest conversion for various uses in the Pugu Forest Reserve including charcoal, fuel wood and agricultural expansion.

Using woodlots to address these energy needs would provide extra carbon storage as well as protecting the Pugu FR. As tree felling is an illegal activity that proceeds due to need and ineffective enforcement, there was no accurate data on volumes extracted for various end-uses. Because so few areas were found to be undamaged, it is difficult to accurately speculate what the carbon density the forest types could reach if allowed to regenerate though one would assume that the carbon level would reach the maximum typical for coastal forests of Tanzania.

Plate 1: Showing destruction of carbon pools for charcoal and wood-fuel

Photo: Goodluck Beda

CHAPTER SIX

6.0 CONCLUSION AND RECOMENDATION

This study provides information on the estimated amount of carbon-storing pools in Pugu Forest Reserve which were low compared to the other studies, indicating an alarming utilization of resources available due to the expansion of human use of the natural environment to supply food, building materials and fuel wood from the forest which greatly degraded carbon density and if left unchecked the potential of the forest to sequester carbon will further be greatly reduced.

In order to increase the potential of this forest on carbon storage local communities around the reserve should actively participate in forest conservation and protection matters particular by introducing Joint Forest Management programmes (JFM) programmes in the forest adjacent villages.

Training should be done by responsible institution such as forest district forest department and other environmental stakeholders to the communities adjacent the forest to create awareness and concern about forest protection to achieve carbon storage potential.

Also initiatives outside the forest to address the community building materials and fuel wood needs especially by house- hold tree planting can make a difference in near future.

To increasing net carbon storage in the area need to entail sustainable management practises accompanied by tree-planting activities inside the reserve to increases carbon storage.

Managing Pugu forest to obtain multiple economic, societal and environmental benefits requires integrated policies and incentives that rehabilitate, maintain and enhance carbon stocks.

Forests provide various ecosystem services that are essential to human well-being, if Pugu given a chance to regenerate, it appears the forest could achieve a greater average carbon density with potential to participate in REDD+ initiatives. The REDD+ initiative is one among the approaches that can achieve multiple benefits from the management of the Pugu Forest Reserve.

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APPENDICES

Appendix 1: Field Inventory Form

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

PSP	Sub-plot	Stem No	Local Name	DBH	Point of Measurement	Height

Appendix 2: A table showing tools used to collect data

Tools	**Activity**
GPS	For boundary guidance and locating plots,
Rope	For plot boundary delineation
Base map plot	For navigation
Linear tape	For locating plot boundary and for distance measurement
Chalk	For marking the trees temporarily before permanent tagging and for ensuring they are measured
Metal tags and hammer	For trees permanent marking and fixing metal tags on tree
Hoe	Digging soil
Nails	For placing the tags
Knife	Sickle for cutting herbs
Weighing machine	Weighing herbs dead wood and leaf litter
Soil sample core	For collecting soil samples from various depths
Trowel	For taking out soil core from the soil depth
Diameter tape/calliper	For measuring the diameter of the tree at breast height

Appendix 3: A table showing list of tree species and carbon stocks found in Pugu Forest Reserve in Tanzania

Botanical name	Local name	Total DBH	LnDBH	Total Bimass in Kg	Biomass in t ha^{-1}	Total t Cha^{-1}	Mean Carbon t Cha^{-1}
Senna siamea	Mjohoro/ Mkenge	1067.9	287.7	2241	28.01	13.72	0.572
Trema orientalis	Mpehe	717.9	200.4	1364	17.05	8.356	0.348
Diospyros verrucosa.	Mburuzu	482.4	121	1239	15.49	7.588	0.316
Commiphora boiviniana	Mpopoma	174.2	35.68	766.1	9.577	4.693	0.196
Xylopia arenaria	Mlawilila	82.8	15.46	754.9	9.436	4.624	0.193
Milicia excelsa	Mvule	41	3.714	749.6	9.37	4.591	0.191
Rourea coccinea	Mkungugu	173.8	39.94	700.3	8.754	4.289	0.179
Nesogordnia holtzii	Mvimbaditwi	195.5	42.38	677.9	8.474	4.152	0.173
Dichapetalum stuhlmannii	Mkomamene	300.6	78.84	677.6	8.47	4.15	0.173
Vitex ferruginea	Mpuya	118.3	24	642.6	8.032	3.936	0.164
Grewia microcarpa	Mkongedeka	149.1	32.45	642	8.025	3.932	0.164
Lannea schweinfurthii	Mjengauwapori	117	23.58	532.6	6.657	3.262	0.136
Erythroxylum fischeri	Mtunda	190.5	46.3	520.3	6.504	3.187	0.133
Ricinodendron heudelotii	Mpira	252.3	72.29	421	5.262	2.579	0.107
Tarenna littolaris	Mshadapori	181.1	46.77	414	5.175	2.536	0.106
Grewia conocarpa	Mkolemwekundu	230.8	65.36	401.8	5.022	2.461	0.103
Turraea mombassana	Mtete	194.4	52.53	390.6	4.882	2.392	0.1
Ludia mauritiana	Mchedi	89.3	20.54	365.6	4.57	2.239	0.093
	Mtalawanda	30	3.401	363.1	4.539	2.224	0.093
Deinbollia borbonica	Mmoyomoyo	84.6	18.35	313.2	3.915	1.918	0.08
Rinorea ferruginea	Mnyakaegele	93.8	23.74	268.7	3.359	1.646	0.069
Afzelia quazensis	Mkongo	88.7	21.23	252.4	3.155	1.546	0.064

Botanical name	**Local name**	**Total DBH**	**LnDBH**	**Total Bimass in Kg**	**Biomass in t ha^{-1}**	**Total t Cha^{-1}**	**Mean Carbon t Cha^{-1}**
Senna abbreviata	Mkundekunde	127.1	35.41	242.3	3.029	1.484	0.062
Grewia goetzeana	Mkolebwamba	127.6	35.68	233.6	2.92	1.431	0.06
Oxyanthus pyriformis	Mkongemweusi	128.3	36.74	218.3	2.729	1.337	0.056
Diospyros consulatae	Mkuruti	37.7	7.561	149.1	1.864	0.913	0.038
Diospyros verrucosa	Mnaki	66.6	17.76	140	1.75	0.858	0.036
Albizia petersiana	Mkenge	32.1	6.985	113.7	1.421	0.696	0.029
Vtex.spp	Mfuru	37.9	8.899	107.3	1.342	0.657	0.027
Turraea robusta	Mbonha	49.4	13.47	97	1.213	0.594	0.025
Xylopia parvifolium	Msakulang'wale	53.6	15.17	91.19	1.14	0.559	0.023
	Mnete	24	4.942	90.36	1.129	0.553	0.023
Pteleopsis myrtifolia	Mgovu	53	15.88	76.71	0.959	0.47	0.02
Dialium holtzii	Mtebeti	84.8	19.98	337.2	4.215	0.459	0.019
	Mdundulungoma	42	11.66	74.93	0.937	0.459	0.019
Markhamia zanzibarica	Mhunungu/ mhonongo	38.7	11.1	64.18	0.802	0.393	0.016
Margaritaria discoidea	Mjafuno	36.8	10.83	56.25	0.703	0.345	0.014
Brachystegia bussei	Mbonha	28.5	7.796	53.93	0.674	0.33	0.014
Sclerocarya birrea	Mng'ongo	13.1	2.573	53.12	0.664	0.325	0.014
Abutilon sp.	Mkozelambewa	26.7	7.508	47.66	0.596	0.292	0.012
Suregada zanzibariensis	Mdimupori	26	7.452	42.99	0.537	0.263	0.011
	Mhombohombo	23.7	7.104	34.04	0.425	0.208	0.009
	Mgemba	18.5	5.419	28.91	0.361	0.177	0.007
Allophyllus sp.	Mdangalalila	13.5	3.819	22.81	0.285	0.14	0.006
Tricalysia sp.	Mpugupugu	12	3.555	18.1	0.226	0.111	0.005
Harrisonia abyssinica	Mkunju	11.8	3.545	16.81	0.21	0.103	0.004
Psychotria lauraceae	Mshadapori	11.6	3.505	16.31	0.204	0.1	0.004
Haplocoelopsis Africana	Mbwewe	6	1.792	8.679	0.108	0.053	0.002
	Mkwangasale	5.5	1.705	7.092	0.089	0.043	0.002
Grand total		6332.1	1613	18110	226.4	109.3	4.555

Appendix 4: A table showing calculation of mean soil organic carbon in different depth

PSP	C%	Bulky density	Depth used in cm	Soil volume in cm3	Mass in Kg/ha	OC/Kg	OC tha^{-1}	Mean Carbon
			0-15cm					
1	3.2	1.0521	15	1500000	1578182	50454.47	50.45	2.523
2	1.71	1.2303	15	1500000	1845455	31478.38	31.48	1.574
3	2.99	0.8994	15	1500000	1349091	40385.17	40.39	2.019
4	2.08	1.2048	15	1500000	1807273	37569.4	37.57	1.878
5	2.04	1.0861	15	1500000	1629091	33312.87	33.31	1.666
6	1.67	1.0861	15	1500000	1629091	27235.3	27.24	1.362
7	2.45	1.3152	15	1500000	1972727	48368.41	48.37	2.418
8	2.01	0.857	15	1500000	1285455	25849.98	25.85	1.292
9	1.37	1.0691	15	1500000	1603636	21914.89	21.91	1.096
10	1.67	0.9164	15	1500000	1374545	22979.79	22.98	1.149
11	1.8	0.9588	15	1500000	1438182	25858.51	25.86	1.293
12	1.34	0.857	15	1500000	1285455	17179.05	17.18	0.859
13	1.15	1.0606	15	1500000	1590909	18308.88	18.31	0.915
14	1.11	0.9503	15	1500000	1425455	15875.7	15.88	0.794
15	1.86	1.0606	15	1500000	1590909	29527.72	29.53	1.476
16	1	0.9248	15	1500000	1387273	13905.8	13.91	0.695
17	1.26	1.0521	15	1500000	1578182	19919.63	19.92	0.996
18	1.19	1.1285	15	1500000	1692727	20108.9	20.11	1.005
19	1.3	1.0776	15	1500000	1616364	21001.47	21	1.05
20	1.19	0.7127	15	1500000	1069091	12700.36	12.7	0.635
Mean Carbon							26.7	26.7
			15-30 cm					
1	1.2	1.2727	15	1500000	1909091	22851.82	22.85	1.143
2	2	1.1964	15	1500000	1794545	35846.05	35.85	1.792
3	1.26	1.1794	15	1500000	1769091	22375.99	22.38	1.119
4	2.86	1.0776	15	1500000	1616364	46209.17	46.21	2.31
5	1.37	1.0521	15	1500000	1578182	21567.04	21.57	1.078
6	1.47	1.1285	15	1500000	1692727	24854.65	24.85	1.243
7	1.54	1.12	15	1500000	1680000	25807.32	25.81	1.29
8	1.37	1.2982	15	1500000	1947273	26610.94	26.61	1.331
9	2.18	1.0606	15	1500000	1590909	34690.33	34.69	1.735
10	1.71	1.2303	15	1500000	1845455	31478.38	31.48	1.574
11	1.37	0.8061	15	1500000	1209091	16607.27	16.61	0.83

PSP	C%	Bulky density	Depth used in cm	Soil volume in cm3	Mass in Kg/ha	OC/Kg	OC tha^{-1}	Mean Carbon
12	2.04	1.103	15	1500000	1654545	33779.25	33.78	1.689
13	0.93	1.1624	15	1500000	1743636	16183.63	16.18	0.809
14	1.26	1.0776	15	1500000	1616364	20401.56	20.4	1.02
15	1.08	1.1879	15	1500000	1781818	19183.3	19.18	0.959
16	0.63	1.1115	15	1500000	1667273	10524.39	10.52	0.526
17	1.63	1.1018	15	1500000	1652727	26994.63	26.99	1.35
18	1	0.8061	15	1500000	1209091	12119.73	12.12	0.606
19	1.45	1.1709	15	1500000	1756364	25427.99	25.43	1.271
20	1.67	0.7976	15	1500000	1196364	19984.7	19.98	0.999
Mean Carbon							24.67	24.67
			30-60 cm					
1	1.23	1.0945	30	3000000	3283636	40451.12	40.45	20.23
2	1.8	1.0012	30	3000000	3003636	53930.29	53.93	26.97
3	1.32	1.1879	30	3000000	3563636	46904.4	46.9	23.45
4	1.25	1.137	30	3000000	3410909	42580.6	42.58	21.29
5	1.54	1.0861	30	3000000	3258182	50050.56	50.05	25.03
6	1.81	1.1964	30	3000000	3589091	64871.74	64.87	32.44
7	1.47	1.2388	30	3000000	3716364	54568.11	54.57	27.28
8	1.06	1.1879	30	3000000	3563636	37822.3	37.82	18.91
9	1.57	1.2218	30	3000000	3665455	57550.02	57.55	28.78
10	1.91	1.2642	30	3000000	3792727	72411.32	72.41	36.21
11	0.85	0.9673	30	3000000	2901818	24779.32	24.78	12.39
12	0.71	0.6873	30	3000000	2061818	14545.38	14.55	7.273
13	1.34	1.0436	30	3000000	3130909	41842.05	41.84	20.92
14	1.3	1.1624	30	3000000	3487273	45310.26	45.31	22.66
15	0.97	1.0776	30	3000000	3232727	31204.51	31.2	15.6
16	1.63	1.137	30	3000000	3410909	55711.69	55.71	27.86
17	1.78	0.7806	30	3000000	2341818	41775.76	41.78	20.89
18	0.89	1.0861	30	3000000	3258182	29031.66	29.03	14.52
19	1.82	1.1964	30	3000000	3589091	65282.45	65.28	32.64
20	1.37	0.6024	30	3000000	1807273	24823.5	24.82	12.41
Mean Carbon							42.73	21.37

Appendix 5: A table showing calculations of mean organic carbon for dead wood

PSP NO	Total Gross Weight	Sample Gross Weight	oven dry weight	oven dry in $1m^2$	OC% in gram	OC in gram	OC in tonnes	OC $t\ ha^{-1}$	Mean Carbon $t\ ha^{-1}$
1	230	71	65	210.563	52.15	109.81	0.0001	1.0981	0.046
2	437	152	103	300.374	106.3	155.85	0.0002	1.5585	0.065
3	148	64	62	143.375	52.7	75.56	8E-05	0.7556	0.031
4	146	83	54	94.988	52.61	49.978	5E-05	0.4998	0.021
5	273	85	60	192.706	49.9	96.164	1E-04	0.9616	0.04
6	297	98	88	266.694	53.12	141.68	0.0001	1.4168	0.059
7	145	98	75	110.969	54.54	60.526	6E-05	0.6053	0.025
8	460	139	116	402.053	110	222.6	0.0002	2.226	0.093
9	322	149	89	227.598	102	111.63	0.0001	1.1163	0.047
10	430	151	103	295.418	103.6	151.99	0.0002	1.5199	0.063
11	396	139	103	293.549	100	146.95	0.0001	1.4695	0.061
12	454	164	95	261.22	108.5	141.64	0.0001	1.4164	0.059
13	83	66	62	77.9697	54.84	42.756	4E-05	0.4276	0.018
13	211	84	40	100.476	55.11	55.369	6E-05	0.5537	0.023
14	240	65	45	166.154	44.86	74.53	7E-05	0.7453	0.031
15	230	59	39	152.034	45.71	69.498	7E-05	0.695	0.029
16	449	150	106	324.856	110.9	181.21	0.0002	1.8121	0.076
17	250	68	48	176.471	55.15	97.326	1E-04	0.9733	0.041
18	188	89	51	107.73	51.76	55.764	6E-05	0.5576	0.023
19	504	150	108	361.624	96.02	170.05	0.0002	1.7005	0.071
20	338	84	50	201.19	47.24	95.047	1E-04	0.9505	0.04
23	300	74	56	227.027	56.04	127.23	0.0001	1.2723	0.053
Total Mean Carbon									1.014

Appendix 6: A table showing calculations of mean organic carbon for litter

PSP NO	Total Gross Weight	Sample Gross Weight	Oven dry weight	Total oven dry per m^2	OC%	OC in gram	OC in tonnes	OC in t ha^{-1}	Mean Carbon in t ha^{-1}
1	105	60	53	92.75	44.88	41.63	4.16E-05	0.416	0.017
2	115	70	72	118.29	39.9	47.19	4.72E-05	0.472	0.02
3	232	133	108	188.23	95.13	89.54	8.95E-05	0.895	0.037
4	132	65	45	91.385	52	47.52	4.75E-05	0.475	0.02
5	249	149	107	184.01	90.03	78.15	7.82E-05	0.782	0.033
6	51	51	43	43	92.83	20.14	2.01E-05	0.201	0.008
7	112	92	70	85.821	93.13	41.49	4.15E-05	0.415	0.017
8	190	78	56	136.41	52.69	71.87	7.19E-05	0.719	0.03
9	157	152	128	131.96	98.37	65.08	6.51E-05	0.651	0.027
10	169	150	109	122.93	99.57	60.77	6.08E-05	0.608	0.025
11	211	146	120	175.84	87.11	76.73	7.67E-05	0.767	0.032
12	122	63	55	106.51	35.38	37.69	3.77E-05	0.377	0.016
13	90	77	64	74.805	46.61	34.87	3.49E-05	0.349	0.015
14	268	143	116	216.12	97.17	104.7	0.000105	1.047	0.044
15	156	117	85	112.05	67.97	41.42	4.14E-05	0.414	0.017
16	90	57	53	83.684	45.9	38.41	3.84E-05	0.384	0.016
17	151	126	116	138.14	104.6	72.25	7.22E-05	0.722	0.03
18	228	136	105	174.7	104.6	91.37	9.14E-05	0.914	0.038
19	120	69	51	88.696	51.76	45.91	4.59E-05	0.459	0.019
20	108	83	55	71.566	48.19	34.49	3.45E-05	0.345	0.014
21	107	63	46	78.127	52.98	41.39	4.14E-05	0.414	0.017
23	67	67	65	65	57.34	37.27	3.73E-05	0.373	0.016
24	88	88	65	65	51.78	33.66	3.37E-05	0.337	0.014
Total Mean Carbon									0.522

Appendix 7: A table showing calculations of mean organic carbon for herbs

PSP NO	Total Gross weight	Sample Gross Weight	Sample dry Weight	Total dry weight	OC%	OC in gram	OC in tonnes	OC in t ha^{-1}	Mean Carbon in t ha^{-1}
1	1282	255	116	612.3	164.49	337.18	0.0003	3.372	0.14
2	687	215	89	277.4	155.69	145.5	0.0001	1.455	0.061
3	150	71	25	52.82	51.984	27.456	3E-05	0.275	0.011
4	283	127	63	142.4	104.58	74.581	7E-05	0.746	0.031
5	80	80	35	35	53.312	18.659	2E-05	0.187	0.008
6	672	202	68	227.9	102.27	116.9	0.0001	1.169	0.049
7	563	270	96	210.4	158.69	112.9	0.0001	1.129	0.047
8	134	74	49	88.73	54.737	48.568	5E-05	0.486	0.02
8	179	144	62	80.96	95.939	39.415	4E-05	0.394	0.016
10	73	73	24	24	50.997	12.239	1E-05	0.122	0.005
13	158	79	62	124	51.554	63.927	6E-05	0.639	0.027
14	138	64	49	105.7	51.448	54.358	5E-05	0.544	0.023
17	312	157	107	212.8	95.517	101.04	0.0001	1.01	0.042
18	504	187	97	234.8	106.18	124.39	0.0001	1.244	0.052
19	285	175	123	200.5	99.237	98.921	1E-04	0.989	0.041
21	113	82	31	42.72	53.424	22.822	2E-05	0.228	0.01
22	1132	227	114	564.4	160.06	299.89	0.0003	2.999	0.125
23	132	56	31	73.07	52.181	38.13	4E-05	0.381	0.016
Total Mean Carbon									0.724

Appendix 8: Aerial picture showing the status of Pugu Forest Reserve Tanzania

Source: Google earth 2012