Comparative evaluation of two forest systems under different management regimes in Miombo woodlands

A case study in Kitulangalo area, Tanzania

Master of Science Thesis in Industrial Ecology

Lina Hammarstrand
Andreas Särnberger

Department of Energy and Environment
Division of Physical Resource Theory
CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden, 2013
Report No. 2013:4

Comparative evaluation of two forest systems under different management regimes in Miombo woodlands
A case study in Kitulangalo area, Tanzania
Master of Science Thesis in Industial Ecology
Report No. 2013:4
© LINA HAMMARSTRAND
© ANDREAS SÄRNBERGER, 2013.

Department of Energy and Environment
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone + 46 (0)31-772 1000

Cover: Picture of one of the two forest systems in Kitulangalo area during dry season.
L. Hammarstrand (2012)

Chalmers Reproservice
Göteborg, Sweden 2013

Table of Content

Abstract

The world forest is a key component in the environmental issue of global warming as it acts as one of the most important storage for carbon. This storage potential gives possibilities to mitigate carbon dioxide emissions and therefore reduce global warming. Despite this, extensive degradation and deforestation of the world forest occurs today and there is a desire from the international environmental community to reduce the destructive degradation and conserve the world forest, especially in Africa where a majority of the world forest degradation takes place. Tanzania is one of these countries where a high deforestation rate is a major issue, especially in Miombo Woodlands, which represent most of the forestland. A number of people and communities that live adjacent to Miombo woodlands are highly dependent on the forest for their livelihood.

This study investigated the condition of two forest systems under different management regimes. One case focused on conserving the forest, named as protected forest, and one case focused on forest accessibility and usability, named as unprotected forest. Furthermore the thesis estimated how these two forests can contribute to the local peoples livelihood as well as discuss what the future potential for these forests may look like.

The parameters measured to assess the forest condition were carbon stock in above-ground biomass, below-ground biomass and carbon content in soil and tree species biodiversity. Data was collected through field measurements. The livelihood potential was assessed by a selection of system services most important for the local people identified through interviews. During the interviews, major threats and drivers for forest degeneration were determined and contextual parameter for these specific forest systems, such as population growth in the area and accessibility of the forests, were included to discuss the future potential of the forests in terms of carbon stock and system services.

The conclusion is that the two forest cases were quite similar for the parameters assessed in this thesis, which was a surprising result since historical studies showed that the protected forest was in a better condition. Furthermore, for some parameters, such as carbon stock and one of the system services, the unprotected forest even showed better results than the protected forest. When discussing the future potential it was concluded that there are two aspects of a forest, the global desire of preservation as well as the local need for usability and resource extraction. The ideal would be to satisfy both of these conflicting wills without further degrading the forest, meaning the extraction rate does not exceed the regrowth rate of the forest. But with the increasing pressures expected in the future it may prove difficult to meet all these demands in a sustainable way on such a small forest area. However, the study concludes that there are many factors that can be improved in the current forest utilisation to increase the forest usage efficiency.

Keywords: Livelihood, Miombo woodlands, carbon stock, biodiversity, system services, charcoal, timber, building poles, above-ground biomass, below-ground biomass, soil organic carbon,

Acknowledgement

The authors of this thesis would like to express gratitude to a number of contributors who have made this thesis possible. First of all we would like to thank our main supervisor from the department of Energy and Environment at Chalmers University of Technology, Madelene Ostwald, for her never-ending participation and commitment to our project from start to end. We would further like to thank all the people at Sokoine University of Agriculture that made the field assessment in Morogoro, Tanzania feasible. A special gratitude goes to Prof. Y. Ngaga and E. Zahabu for all the valuable information that you gave us. You helped us with practicalities and really went far beyond our expectations. Acknowledgement is extended to L. Mbwambo at Tafori, Prof. Shio, Prof. B. Makonda, C. Mhaiki, Prof. B.M. Msanya, Prof. S.A.O Chamshama and Ph.D.c E. Edwards for their time and expertise. Thanks to our translators Lulu Hassani and Sam Shaba and to our forest guide Juma for their commitment and contribution to the tough fieldwork.

We would also like to send acknowledgement to our financial sponsors from the Minor Field Study program at SIDA and the founding from Ångpanneföreningens Forskningsstiftelse whom made this project economically feasible. Additional thanks go to Gert Nyberg at Swedish University of Agricultural Science, our examiner Stefan Wirsenius and Ph.D.c Lisa Westholm at Chalmers for contribution and input to the thesis.

1.1 Introduction

The following introduction chapter presents background information about Tanzania and the problems with degradation of the Miombo woodlands. The concept of sustainable forest management is emphasised and a presentation of the purpose, research questions and scope of this study are included.

1.2 Background

1.2.1 Degradation mechanisms of Miombo Woodlands

The world forests are vital carbon sinks as they store significant amounts of biomass and therefore provide the earth with a global system service in terms of carbon storage. The carbon stock can both increase and decrease from anthropogenic actions. An increase in the world's carbon stock occurs when humans take actions such as; sustainable forest management, plantation and rehabilitation and conserving the global forest. While actions such as; deforestation, degradation and lack of forest management decrease it (FAO, 2010). Today a degradation of the world's forest resources is taking place, although the rate of degradation has been slowing down in the last couples of years (FAO, 2010). Deforestation is major problem in Africa, approximately 65 % of the world forest decline between 2000-2010 happened on this continent according to estimate preformed by FAO (FAO, 2010). Tanzania represent one of the countries where deforestation occur to a significantly high rate, approximately 403 000 ha per year calculated during 2000-2010 (FAO, 2011). That amount equal an annual forest decrease of more than 1 % for Tanzania with its total forest area of 31 million ha (FAO, 2010). A majority of the forest in Tanzania consists of the forest type Miombo woodlands and it is in this type of forest most of Tanzania's forest degradation occurs (Isango, n.d.). Miombo is one of the largest dry tropical seasonal forests in the world (Obiri et al., 2010) that covers large parts of southern, central and eastern Africa. It is widespread over countries such as Angola, Zimbabwe, Zambia, Malawi, Mozambique and Tanzania and most of the southern part of the Democratic Republic of Congo (Campbell et al., 1996). Miombo woodlands has Africa's most diverse flora with the widest range of vegetation types (The united republic of Tanzania, 2001).

The high degradation rate of Miombo woodlands could be explained by the high usage of the forests due to its ability to provide resources such as food, energy, shelter, medicines, environmental and spiritual services for millions of rural and urban people living close to Miombo areas (Campbell et al., 1996). The extensive use of forest resources to fulfil people's livelihood results in high anthropogenic pressure on the woodland. Degradation mechanisms are mainly large-scale conversion to industrial agriculture, shifting cultivation, charcoal production and increased resource extraction to fulfil urban demands. The growing population is also a significant factor that put even higher pressure on all the above mentioned mechanisms (Campbell and Byron, n.d.). If Miombo woodlands continues to act as a resource bank for people's livelihood there is a need of preventing the degradation and preserve the forest to ensure future usability as well. A continued degradation could result in a loss of some vegetation types and decrease the overall biodiversity. Miombo woodlands are expected to meet the needs of today and at the same time meet the need of conserving Miombo, its carbon stock and its biodiversity. This reflects the issue with sustainable development to meet today's needs without undermining future generations possibilities to fulfil their needs. Meeting everyone's needs is not the case today and, if resources continue to be extracted as they have been, Miombo woodlands will eventually be extinct. An alternative would be to create a system where resources are extracted but to a rate that is sustainable. The concept of sustainable forest management is therefore introduced.

1.2.2 Sustainable forest management (SFM)

The Montréal Process, International Tropical Timber Organization, FOREST EUROPÉ, and the Food and Agriculture Organization of the United Nations' (FAO) Global Forest Resources Assessment have agreed on, and promotes, sustainable forest management as described by United Nations Forum on Forests: "Sustainable forest management, as a dynamic and evolving concept, aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations." The concept has been implemented to seven internationally recognized thematic elements of SFM (The Montréal Process, 2012), used as basis for monitoring and reporting forest conditions throughout the world and act as a non-legally binding instrument on all types of forest .

1. Extent of forest resources
2. Biological diversity
3. Forest health and vitality
4. Productive functions of forest resources
5. Protective functions of forest resources
6. Socio-economic functions
7. Legal, policy, and institutional framework

This concept provide a basis for monitoring and reporting which is essential when comprehending and reducing unplanned deforestation, restore and rehabilitate degraded forest landscape and when assessing the significant function of carbon sequestration by forest and other wooded lands (FAO, 2010). Forest area often exclusively provides a basis for monitoring and is used as an indicator for the extent of forest resources, but this indicator is not adequate. It does not display the health of the forest, what type of forest that is measured, how it is managed and its potential in providing services. A variety of other parameters are needed for that determination (FAO, 2010). The optimal would be to measure all parameters included in SFM to get a holistic view of a forest condition but that is a very time consuming process. The performers of this study have therefore chosen to focus on parameter 1, 2 and 4 in SFM.

1.2.3 Studied area

To study the dilemma of either conserving the biomass and biodiversity or to extract the forest resources, an area where both cases are represented needed to be found. These two cases are represented in a forest reserve in Tanzania called Kitulangalo and forest areas in the surrounding villages to Kitulangalo. This study is carried out in those areas and a more detailed description about the location and management systems follows.

Kitulangalo forest reserve is a semi-dry low altitude Miombo woodland with an area of 1700 ha that is located 50 km east of Morogoro along the highway towards Dar es Salaam. Historically the government have used the reserve as a 'productive reserve' meaning that it has been controlled by mandatory possession of license for wood production since 1955 (Malimbwi et al., Not published). Harvesting was forbidden in 1985 even though illegal utilisation still occurs (Malimbwi et al., Not published) and in 1995 the reserve was divided into two parts. One part stayed under the central government's management and the remaining forest stayed under Sokoine University of Agriculture's management (SUA). The area of the central governmental part and SUA's part represent an area of 1200 ha and 500 ha respectively (Lulandala, n.d.). Both management systems have intention to conserve the biomass and biodiversity, yet both forests have problems with illegal utilisation. However, the problems are less extensive in SUA's part, because it has been more strictly protected from harvesting with visible guards and, additionally, clear borders and regularly maintained fire lines surrounding the area (Lulandala, n.d.). This study is limited to the part managed by SUA and that part represent the forest case which has the purpose to conserve biomass and biodiversity.

Adjoining to Kitulangalo forest reserve are the two villages Gwata and Mazizi, which are open-access public land that represent Miombo woodland exposed to high rate of resource extraction (Obiri et al., 2010) both for domestic and external use. Therefore these areas were chosen to represent the forest case were forest resources are extracted. This forest is without central legal protection and is owned by local governments (Malimbwi et al., Not published). Large parts of Miombo woodlands in Tanzania falls under this type of ownership (Malimbwi et al., 2001).

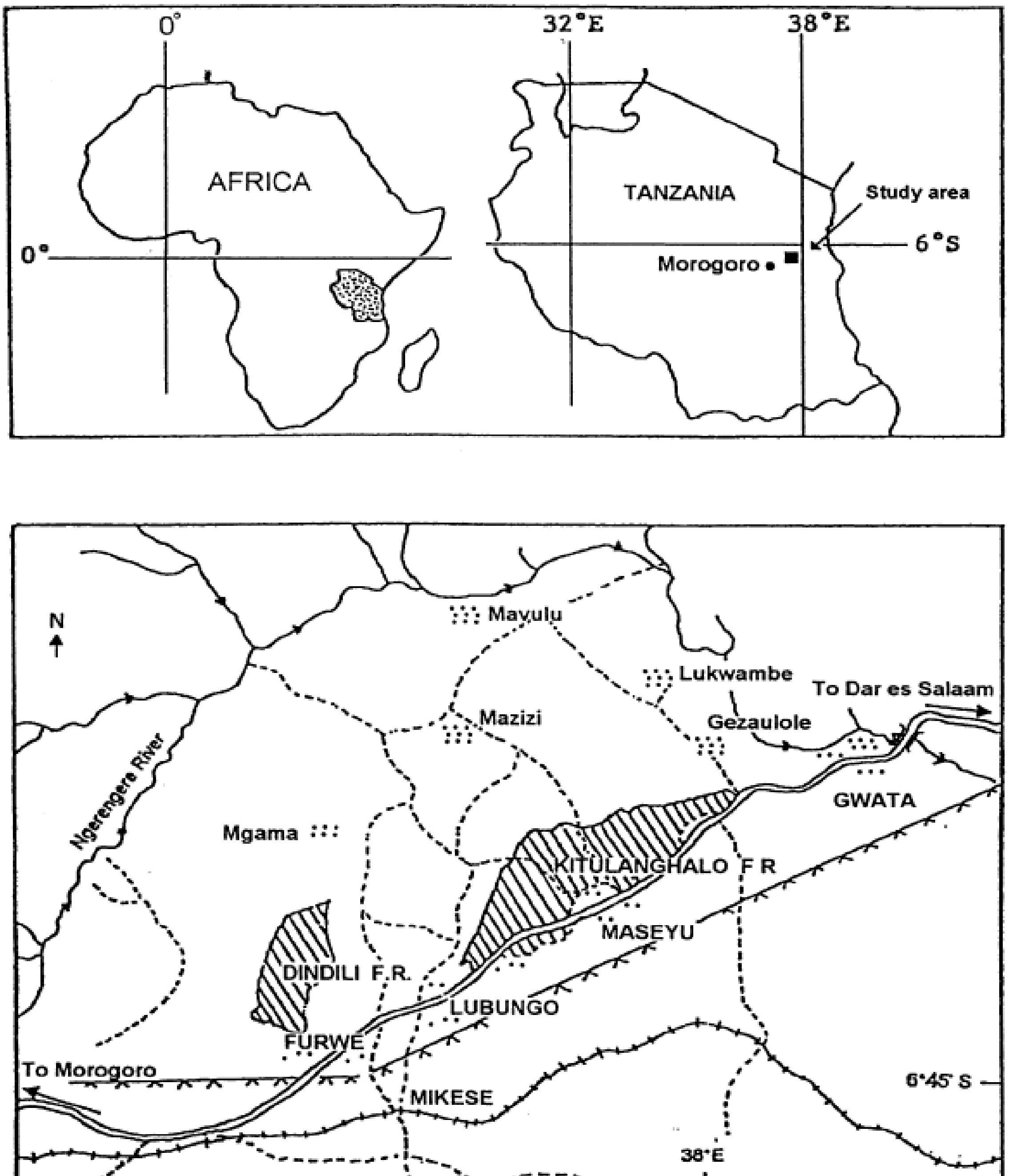


Figure 1; A map of the studied area for Kitulangalo forest reserve, Gwata and Mazizi and the studied areas location in Tanzania (Luoga et al., 2002)

The two forest cases consists of Miombo woodland which are defined as an open cover of trees, with crowns that do not form an interlaced canopy. Miombo is distinguished through three closely related genera of trees *Brachystegia, Julbernardia* and/or *Isoberlinia* from the legume family (*Fabaceae, subfamily Caesalpinioideae*), and they are rarely found outside Miombo (Frost, n.d.). Miombo woodlands can be classified as Wet Miombo woodlands if the annual rainfall exceeds 1000 mm per year or Dry Miombo woodlands if rainfall is less than 1000 mm (Frost, n.d.). The two forests in this study falls under the second classification with an average annual rainfall of 890 mm (Holmes, 1995). The wet season of this dry Miombo forest propagates all the way from October to May, while the rest of the year is characterized as dry season (Holmes, 1995). The variation in temperature over the year is low in Morogoro as in most part of Tanzania with an observed maximum temperature of 36.7°C and a minimum temperature of 9.2°C (Holmes, 1995).

1.3 Purpose and research questions

The purpose of this study is to determine the condition of two forest systems by estimating the total carbon stock in above-ground biomass, below-ground biomass and the carbon content in soil and tree species composition. These parameters were measured since they could be connected to conservation of carbon stock and biodiversity. This was done in two forest systems with different management schemes, which has been described in detail in the introduction. The first one is managed with restricted access in terms of resource extraction with an ambition of forest conservation and is called i) protected forest. The second forest is managed with a focus on accessibility of forest resources and is called ii) unprotected forest. Case i) protected forest is done in the part of Kitulangalo managed by SUA and the case ii) are located in the public land next to the villages Gwata and Mazizi (Figure 1) close by Kitulangalo forest reserve. The purpose is also to identify the most important pressures to the two forest systems and to identify the most important system services for the local people in terms of resource extraction. The most important system services are quantified in order to evaluate the two forests abilities to provide these services. The following four research questions have been analysed:

1. *How large is the carbon stock in above-ground and below-ground biomass and what is the soil carbon content, in two forest systems?*

2. *Does the biodiversity of trees differ between the two forests?*

3. *Which system services are most important for the local people in order to contribute to their livelihood and what are the possibilities for the two forests to provide these services?*

4. *What are the major pressures for these specific forest systems and what are the possible future potentials in terms of carbon stock and system services?*

2 Materials and methods

The methodology, to answer the research questions in this study, was divided into three parts i.e. field assessment, literature study and interviews. The field assessment of the two forests was conducted by measuring height and diameter at breast height (DBH) of the trees, tree species and collecting soil samples. These measurements was then used to give estimations of above-ground biomass, below-ground biomass and carbon content in soil to give an overview of the carbon stock and also the biodiversity. Interviews with the local people and researchers within the field were preformed to identify major pressures and most important system services for the local people. A literature study was done to identify which system services that could be connected to specific tree species and tree size limits. They were quantified in order to evaluate the two forests abilities to provide these services.

2.1 Constructions of the plots, placement and sample collection

Plots for the protected forest were placed along transects from Dar es Salaam highway straight into Kitulangalo forest and the public land next to Gwata village. Transects for the unprotected forest were placed in the public land of Mazizi with the starting point at the Mazizi road. The transects were placed perpendicular to the access point, the roadside in this case, because pressure on forest was dependent on distance from the access point. This was noted by Malimbwi, Zahabu and Monela, (2001) who concluded that forest close to the highway in their study was degraded while further away from the highway it was in better condition. A schematic map of the plot locations can be seen in Figure 2.

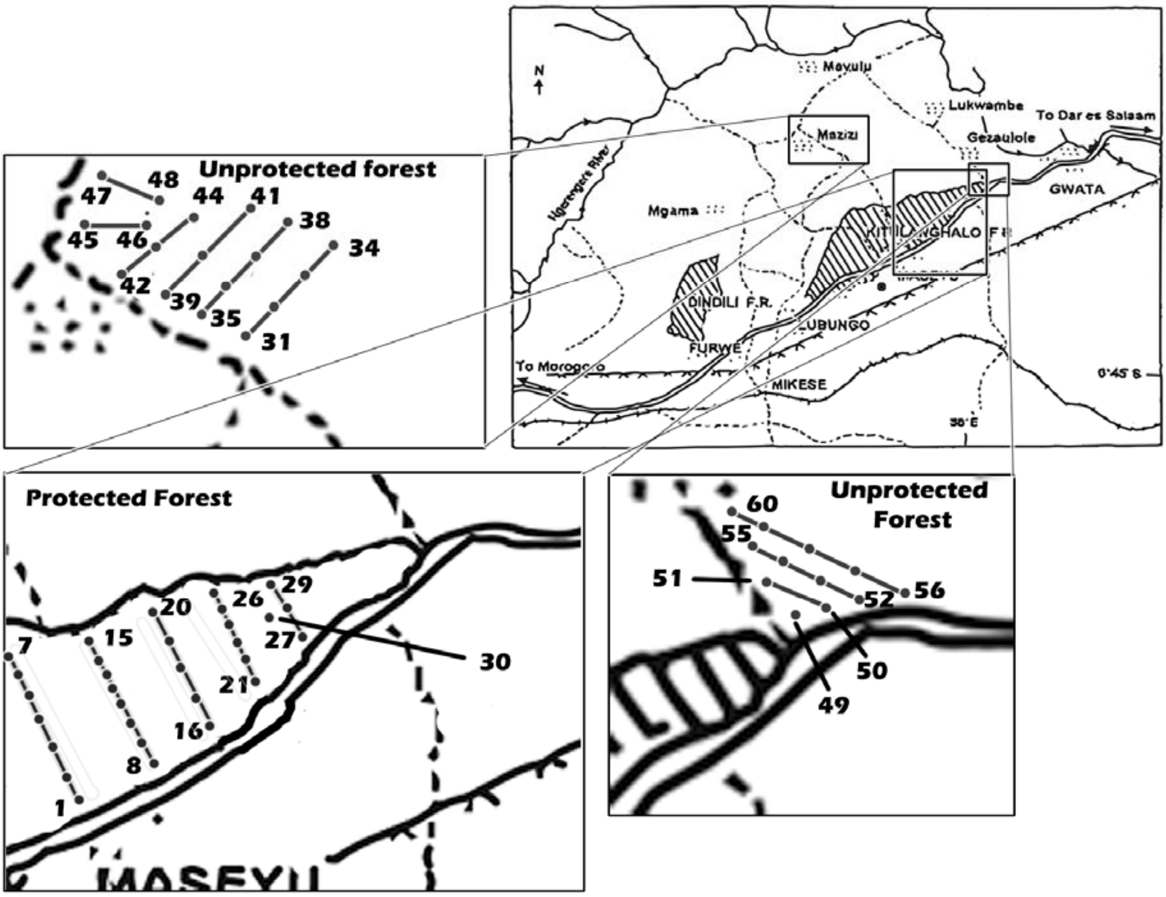


Figure 2; Map of the area (seen top right) (Luoga et al., 2002) and Schematic overview of the 60 plots used for field measurements placed in transects. For the protected forest 30 plots were located in the Kitulangalo forest reserve (seen bottom left). For the unprotected forest 30 plots were divided in two clusters, located close to Gwata (seen bottom right) and Mazizi (seen top left)

All plots were distributed randomly as GPS coordinates were defined in advance. The plots located in the protected forest were placed at the same GPS coordinates as Tafori's plots in 2004, for exact coordinates see Appendix X. A flat topography is common in Kitulangalo forest reserve, which is beneficial in order to decrease the risk of errors for e.g. plot area when taking vegetation measurements (Pearson et al., 2005). An additional reason why it is advantageous to avoid plots in subscripted landscape is because carbon usually accumulates there (Nyberg, personal communication, September 28 2012). In the few cases when a sloping topography occurred and when the GPS coordinates were situated in a water source, the plots were moved to another location. Standard shape of plots used in vegetation studies are rectangles and squares, even though strips and circles is also common (Ravindranath and Ostwald, 2008). Circular sample plots were chosen in this study, with a radius of 15 m, because that shape have been used in previous studies for the protected forest.

Plot size and number of plots is something that should be considered thoughtfully since it affects several significant factors, for instance it reflects the question of time and cost within a project. A high number of plots and large plot size increases the time and cost of a project. It is important to make sure that the time and cost do not exceed limitations of the project without undermining the quality of the study (IPCC, 2003). A high number of plots and a large plot size increase the level of precision but a large plot size is not always needed. It is needed in heterogeneous populations to get accurate precision (IPCC, 2003) but not in homogenous vegetation type as is the case of the two forest cases used in this study, since Miombo in general consists of a few dominant species. Number of plots was set to 30 in each forest and this decision was based on size of trees, size of project area and variation of standing density (Ravindranath and Ostwald, 2008).

The parameters chosen for measurements in this project were; identification of tree species, the frequency of each species per unit area, the diameter at breast height (DBH) that was measured 130 cm above-ground level and the tree height. DBH and height were measurements needed for the above-ground biomass equation and they were measured by using a caliper and a clinometer. The measurements of herbaceous and trees with a DBH below 10 cm were excluded according to recommendations by Mbwambo (personal communication, December 4, 2012) with the motivation that collecting measures for trees below this limit would be a very time consuming process. These small trees were also vulnerable for disturbances e.g. wildfires, which decreased their probability of contributing to the biomass stock over time. Another reason was the fact that a DBH of 10 cm was the threshold for providing services such as building poles and charcoal (Mbwambo, personal communication, December 4, 2012). A local tree specialist who works as a forest guide in the area identified tree species in the field. He identified the local tree name which was later translated into the botanic name through checklist specially developed for Tanzania (The United Republic of Tanzania - Ministry of Natural Resources & Tourism, 2010), previous literature about Kitulangalo forest reserve and by scientists at SUA.

The soil samples were collected from four locations in each plot with a distance of 5 m from the circle's mid point. Circular samples were collected with a radius of 5 cm and equal amount of soil was collected at a depth of 10 cm, as carbon content varies with depth and is often higher in the top soil (Nyberg, personal communication, September 28, 2012). The four soil samples at each circular plot were collected and mixed into one sample in a paper bag that allowed the soil to dry in air and thereafter transported to the laboratory of SUA for analysis.

2.2 Carbon stock

The first thematic element of SFM is closely connected to the overall goal of SFM to preserve adequate forest resources of numerous forest types and characteristics, which also includes other wooded land such as Miombo woodlands. Growing stock and carbon storage are measurements that have the possibility to display if a forest is degraded and to what degree it mitigate climate change (FAO, 2010) and were therefore chosen as a parameters in this study. The carbon stock in terrestrial ecosystem consists of above-ground biomass, below-ground biomass, soil organic carbon, deadwood and litter although deadwood and litter are excluded in this study due to time constrains and the fact that deadwood is often removed to be used for firewood (Luoga et al., 2000).

2.2.1 Above-ground biomass (AGB)

Above-ground biomass is the largest carbon pool in terrestrial ecosystem and represent approximately 80 % of the total biomass in Miombo woodlands (Malimbwi et al., 1994). The biomass usually consists of 50 % carbon but that diverge among species, substrate and locations (Jain et al., 2010; Lamlom and Savidge, 2003). AGB is consequently an important parameter to study when performing studies of the carbon stock in terrestrial ecosystem and the effects of deforestation on the global carbon balance (Ketterings et al., 2001). Carbon is present in living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds and foliage (Ravindranath and Ostwald, 2008).

The most accurate method when estimating the above-ground biomass is to cut down and weight the trees' biomass. That is an extremely time consuming and costly process that does not benefit the reforestation process of a forest. It is therefore limited to studies of small plots (Ketterings et al., 2001). The process of weighting tree's biomass is nevertheless needed when developing allometric biomass equations, either equations for specific species of trees or mixed-species for a specific forest types. They can be utilised in methods that only measure the diameter and the height of trees. Species-specific equations is the most accurate method of the two as species might differ in tree shape and wood density, which influence the total biomass of the tree (Ketterings et al., 2001). Despite this they are seldom developed due to the fact that it is time consuming to construct an equation for every species and also to apply them, especially in forest types with a high variety in tree species. In the absence of constructed species-specific equations there are often mixed-species equations developed for specific forest types (Ketterings et al., 2001), which are preferable to a model developed for forest in general. Mixed-species equations, which were applied in this study, are based on site-specific relationship between height and diameter and the average wood density.

At least two different sets of mixed-species equations for above-ground biomass have been developed specifically in the studied area of Kitulangalo that could also be used generally for Miombo Woodlands, Malawi et. al (1994) and Chamshama et. al (2004). The model constructed by Chamshama et. al (2004) was used in this study since that model is the most recently developed model. Four equations were constructed in Chamshama et. al (2004) and analysed in terms of coefficient of determination (R^2), standard error of estimate, intercept coefficient, bias or unbiased residuals and line of fit plots and additionally by few input parameters. All four equations were compared with the previous developed model by Malimbwi et. al (1994) and the new models were revealed to be better than the old one, which creates another reason to select this newer model. Among these four equations the one that had a high R^2 (it is desirable to have R^2 close to one), was unbiased for the estimation of total biomass with diameter at breast height (DBH) and included the height. It is preferable to include the height in biomass equations since that reduces the standard error (Chave et al., 2005). This equation is presented below (Chamshama et al., 2004):

$$Y = b_0 \cdot D^{b_1} \cdot H^{b_2} \qquad (1)$$

Where Y = Above-ground biomass (kg/tree); D= DBH (cm); H=tree total height (m); b_0, b_1 and b_2 are regression coefficients dependent on selected input parameters. They are equal to: b_0=0.0263; b_1=1.505 and b_2 =1.762 when using DBH and height as input parameters and when calculating biomass (Chamshama et al., 2004). After summarizing the total biomass of all trees within a plot a conversion from biomass per plot to biomass per hectare (kg/hectare) was made. This was done by using the area of the plot with the following calculation:

$$Y(tonnes/ha) = \sum Y(kg/plot) \cdot \left(\frac{\pi \cdot r^2}{10000}\right) \cdot 0{,}001$$

The area of each plot is equal to πr^2 and the plot had a radius of 15 m. 10 000 equalize the conversion factor from m^2 to hectare and 0,001 represent the conversion factor from kg to tonne biomass.

Equations for above-ground biomass are developed by harvesting small number of trees, which gives an uncertainty when applying them on a large scale as they might not be representative for the whole forest (Chave et al., 2005). To verify this uncertainty it is good to compare the result from the applied allometric equations with another developed equation as was done in this study. The result from calculations by using equation 1 was compared with an equation developed for dry tropical forest that has been selected as the best above-ground biomass equation among six different equations by Chave (2005) and it follows:

$$\langle AGB \rangle_{est} = \exp(-2{,}187 + 0{,}916 \times \ln(\rho D^2 H)) \qquad (2)$$

AGB=Above-ground biomass (kg); ρ=density(g/cm^3); D=DBH; H=height

The primary difference between the two equations is that equation 2 includes densities for specific tree species. It would be preferable to include these values, as densities are unique for each tree species, unfortunately these data is lacking for tree species in the specific forest and in the absent of these values a density of 0,5 g/cm^3 was applied. That is the most frequent value among species in tropical Africa according to a study where 282 were investigated (Reyes et al., 1992).

2.2.2 Below-ground biomass

The below-ground biomass is defined as the total biomass of all live roots (Ravindranath and Ostwald, 2008). Quantification of this carbon pool is essential since it stands for 10-40 % of the total biomass in Miombo Woodlands (Zahabu, 2008) and different method are available for that quantification.

Quantification of biomass could be a relatively complex process if a direct method is used. That methodology includes physically measuring the roots, which would be extremely time consuming and destructive, resulting in high costs and an actual contribution to the degradation of forest. Superior methods are to use indirect methods such as allometric equations or a root to shoot ratio. The two methods are both highly connected to the above-ground biomass and dependent on that estimation. There is a specially developed root to shoot ratio for Kitulangalo and Miombo woodlands that can be used extrapolate the below-ground biomass from the measured above-ground. The below-ground biomass stands for 20 % of the total biomass (Malimbwi et al., 1994) according to previous studies in Kitulangalo, resulting in a root to shoot ratio of 0.2.

2.2.3 Calculation of confidence interval for above-ground and below-ground biomass

The results of above-ground and below-ground biomass and carbon stock are presented as a confidence interval since that gives information on the precision of the estimate. The expected value from a study obtains the random parameter in average, in this case the average value of biomass. To know how much this value may vary it is also important to estimate the average deviation from the expected value. If the derivation and the expected value are not known as in the case for this study, they can be obtained by equation (3) and (4), where s is the derivation, x is the expected value and n is number of measurements/plots.

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - x)^2} \qquad (3)$$

$$x = \frac{1}{n}\sum_{i}^{n} x_i \qquad (4)$$

When s and x have been calculated an estimation of the confidence interval can be made with equation (3), where t is a value obtained in a standard t-derivation table with the significant level α and n-1 degree of freedom.

$$\left[x - t_{\alpha/2}(n-1)\cdot \frac{s}{\sqrt{n}}, x + t_{\alpha/2}(n-1)\cdot \frac{s}{\sqrt{n}} \right] \qquad (5)$$

30 plots for each forest case have been measured in this study and that equalize a t-derivation value of 2.04. A significant level (α) of 5 % was applied since that is a standard value normally used and it gives accurate precision of estimate for this study. The results are thus presented as an interval where the expected value is included with 95 % probability (Vännman, 2002). All the above-mentioned calculations were calculated by using matlab.

2.2.4 Determining carbon content in soil

Carbon in soil can be separated into three forms: elemental carbon, organic carbon and inorganic carbon. The main sources for elemental carbon (e.g. charcoal, soot, coal, graphite) are either from incomplete combustion of organic matter or from the lithosphere. Inorganic carbon in soil is commonly found as carbonates, mostly minerals calcite and dolomite (Bisutti et al., 2004), and the main source is the lithosphere. Organic carbon on the other hand can be found as a derivate of decomposition of organic matter or through emissions from human processes, ranging from artificial chemicals to natural compounds but with anthropogenic origin e.g. saw dust. Organic carbon comes in a variety of compounds, from simple sugars to carbohydrates, fats, proteins and organic acids, and can range from freshly fallen organic litter to highly decomposed humus.

In general the soil of Kitulangalo is relatively uniform and soil texture is predominantly sandy loam in topsoil grading to sandy clay loam and sandy clay with depth. Desanker and Walker (2004) suggest in their findings that the soil type is correlated with carbon content in the soil, where clay dominated soils have the highest carbon levels. However, the most significant parameter for carbon levels was determined to be soil depth.

There are several ways to quantify total organic carbon in soil but the principle is the same for all measurements, comprising of converting all carbon compounds to carbon dioxide (CO_2) and then measure, either direct or indirect, the evolved amount gas. The direct methods measures the organic carbon content in soil directly from the evolved amount of CO_2 while the indirect methods derive the organic carbon content from measurements of total carbon content, inorganic content and organic matter. At the soil laboratory of SUA they use Walkley-black wet oxidation method for determining organic carbon in soil. For more details on the laboratory instructions see Appendix I. Bisutti et al. (2004) have preformed an extensive evaluation of current methods for determining the total organic carbon content, in this thesis only a short summary of the other methods available, other than the methods used in this study, is given. Most methods for determining soil organic carbon fall under the category of oxidizing the organic carbon and these methods can be divided into three branches; (1) chemical oxidation; (2) dry combustion; (3) wet combustion (Bisutti et al., 2004). For combustion methods, (2) and (3), the CO_2 evolved is measured with an elemental analyser while measurements from chemical oxidation is based on calculations from the remaining unreacted oxidation agent.

The Walkley-Black method for determining soil organic carbon is described as a rapid and approximate determination of soil organic carbon (Walkley, 1947 cited in De Vos et al., 2007). The method is based on the principle that organic carbon is oxidized by using aqueous potassium dichromate, $K_2Cr_2O_7$, as oxidising agent while adding concentrated sulphuric acid, H_2SO_4, as heat source to induce the reaction. Unreacted dichromate is then determined, using ferrous sulphate and then used to calculate the amount of easily oxidisable organic carbon. However, the WB method is based on some important assumptions; the heat from the dilution of acid in water is not enough for complete oxidation and so a correction factor was introduced by Walkley & Black to compensate in the calculations and it was assumed to 1,32 (Walkley & Black 1934 cited in De Vos et al., 2007), which corresponds to a recovery rate of 76 %; only carbon is oxidised during the chemical reaction and any other compounds present in reduced form in the sample, and thus susceptible to oxidisation, is of negligible amount (Bisutti et al., 2004).

Nelson & Sommers (1982) cited in De Vos, et al. (2007) stresses that the correction factor used in WB method is highly soil dependent thus obtained results when using the method should be regarded as approximate. There are many studies where the authors have concluded that a soil-specific correction factor is needed; (Sanmanee and Suwannaoin, n.d.) calculated adjusted correction factor for agricultural soils in Thailand and, found different correction factors with regards to soil texture and soil type. De Vos, et al. (2007) concludes that forest soils need an adjusted correction factor for the specific forest and that an un-modified correction factor may give an error in total organic carbon of samples with 10-15%. On top of the correction factor uncertainty comes other errors linked to the uncontrolled reaction temperature and variation in sample particle size. The outcome of WB is highly dependent on the carbon compound composition of the soil because some compounds can resist wet oxidation. Nelson & Sommers (1982) cited in De Vos, et al. (2007) suggests such compounds to be charcoal, soot, coal and graphite. Research by Hussain & Olson (2000) cited in Krishan, et al. (2009) suggests more stable organic carbon in the mineral fraction of the soil can resist oxidation. For further information about the laboratory procedure for wet oxidation see Appendix I.

2.2.5 Particle size analysis – Soil texture

The soil texture gives much information about the soil because it has a high significance for several parameters both physical and mechanical properties of soil as well as for all properties connected to water content ("Particle Size Analysis," 2006). The connection between soil texture and soil carbon content is put into focus by Desanker and Walker (2004) who suggests that the carbon soil content is significantly positive correlated both silt content and clay content in the top layers of soil, where clay has the highest significance to be positive correlated to carbon. Thus high clay content yields high carbon content, which is believed to be due to pores in the clay, which captures and immobilises the carbon and makes it inaccessible for microbial organisms to utilise.

Soil texture is determined by particle size and the general process for the analysis is initially a dissociation of soil into smaller particles in a suspension followed by a separation by sedimentation. The particle type is determined by based on diameter that is either below or equal to a given threshold thus separating them into three different size categories. Proportion of these categories then determines the soil texture type. The three categories are sand, silt, clay in dropping order with respect to diameter ("Particle Size Analysis," 2006). For further information on the laboratory procedure of particle size analysis see Appendix II.

2.3 Estimation of Biodiversity

Biodiversity can be connected to the second element of SFM and is defined as the variety of existing life forms, the ecological roles they perform and the generic diversity they contain (FAO 1989 cited in FAO 2010). Measurements parameters could include diversity among species, ecosystem, landscape, populations, individuals and genera. However the biodiversity measurements in this thesis focus exclusively on tree species due to time constrains. It is vital to assess, monitor and report on biological diversity to state the condition of a forest and guide towards sustainable forest management. To get the overall condition of biodiversity is difficult due to the complexity of nature and the complications of equalize biodiversity to single measurement parameters. Instead of deciding on a single measurement parameter e.g. species richness that varies tremendously between different ecosystems it is better for policy and monitoring purposes to measure if a change in biodiversity from historical values and if conservation of ecosystem specific species has occurred (FAO, 2010), which has been done in this thesis. Species richness is the main focus and a relevant measurement is the ten most common species in an ecosystem (measured by their share of total growing stock) in order to verify the species composition of a forest (FAO, 2010). This presentation allows for a comparison with previous studies in the protected and the unprotected forest to conclude if a change in biodiversity has occurred and if Miombo specific species has been conserved. In the field all species, which fulfilled the requirement of a DBH above or equal to 10 cm, within each plot were determined to quantify total amount of species and then presented as the 10 most common species.

2.4 Interview methods

Part of this study is to get indications of what local people need from the forest, what system services that are most important and if they want to extract more system services to feel satisfied and moreover to get indications of the perceived conditions of the two forest cases and the possible future threats. One way to get these indications is to ask the local people in a structured manner; this theory background is an introduction to how one can use the tools of qualitative analysis to perform interviews.

The qualitative analysis concerns research to answer questions beginning with: why? how? in what way? It can answer questions which are hard, or even impossible, to approach with a quantitative analysis, which focuses more on questions such as: how much? how many? How often? Qualitative analysis is used to understand why people behave the way they do and how they are affected by the events of their surroundings. Qualitative analysis is a tool to shed light on opinions and attitudes for a certain issue and can be used to describe social phenomena as they occur naturally (Hancock, 1998).

There is a vast number of methods available for qualitative analysis. One of those methods is the case study and it can range in complexity from an advanced analysis of a social situation over time to the more simple form, an illustrative description of an event and its context (Hancock, 1998). Performing a full-scale qualitative study is a complex and time consuming process far exceeding the scope of this thesis. Rather than following one of many available methods in qualitative studies the authors of this thesis were inspired by the methodology of case studies presented in (Baxter and Jack, 2008) with the character of an illustrative description but the methodology was applied in a simpler form.

2.4.1 Different qualitative interview methods

The qualitative analysis can be performed in various ways, depending on focus and one way is the case study approach which can be used when having a specific situation with the aim of exploring a phenomena of interest within its context rather than the underlying phenomena itself. One of the major strengths with the case study is that it allows the researchers to investigate one case from many different angles, to help reveal and understand a situation which could be very hard if using only one perspective (Baxter and Jack, 2008). On the other hand common critique towards the case study approach is that it is very dependent on specific local parameters and context and this lowers the possibility to draw generalised conclusions useful for other studies (Baxter and Jack, 2008). An alternative to the case study approach would be phenomenology, a qualitative analysis that, in similarity to the case study, focuses on the phenomena but unlike the case study, does not put an emphasis on the context but on the phenomena itself. A phenomenology study might be done in similar manners as the case study in this thesis, e.g it could be to investigating what an "important system service" is and what it means to the local population. However, it would disregard the context of two forests located very close to each other and that they are under different management regimes. With a less distinct focus on the contextual parameters of the scenarios it would most likely increase the possibilities to draw generalised conclusions from the results. That means the conclusions could be applied for other studies and thus increasing the scientific value of the results (Hancock, 1998). The case study approach was chosen because of the rather unique situation in Kitulangalo with contextual parameters, which had too high significance to be disregarded. Those contextual parameters are that the two forests with easy access from the highway; they have different management regimes and much research have already been performed and documented for this area.

Interview techniques can range from in-depth interviews to structured questionnaires. The first of these is a technique where the interviewee is allowed to speak freely with no pre-constructed questions, and the interviewer pick up on interesting reasoning and decide which tracks to follow further. The latter is the structured questionnaire with a series of multi choice questions. Both techniques have pros and cons, the in-depth interview requires both skill and experience from the interviewer to guide the interview in the direction needed to answer the researchers question and results from different interviews may be difficult to compare. But if done right can reward the researcher with high quality information (Baxter and Jack, 2008). The answers from a structured questionnaire are easily comparable but leave little room for the individual experiences of the interviewees to shine through. In between these two contrasting techniques is the semi-structured interview, which uses a series of pre-constructed, open-ended questions as basis for the interview but with the option to ask further specifying questions for any interesting reasoning (Baxter and Jack, 2008).

"In-depth and semi-structured interviews explore the experiences of participants and the meanings they attribute to them. Researchers encourage participants to talk about issues pertinent to the research questions by asking open-ended questions, usually in one-to-one interviews. The interviewer might re-word, re-order or clarify the questions to further investigate topics introduced by the respondent" (Cited from Tong et al., 2007).

For this thesis the semi-constructed interview methodology was chosen, since the structured questionnaire probably would not highlight the sought-after attitudes enough and the in-depth interview was beyond the skill and experience of the authors. The questions asked to researchers and local people contain some differences, the questions to the researchers are more abstract and contain technical terms. Originally the questions were identical but on suggestions from professors, supervisor and translators the questionnaire for local people was "simplified".

2.4.2 Processing collected interview data

While the interview should focus on important issues for the case study and on how to capture the interviewees experiences and opinions in an unbiased way, it is equally important that data from the interview is properly handled so the information can be both stored and preserved intact for the after coming analysis phase. This is commonly done with recording devices and taking notes during the interviews, which is later transcribed to a single document. A human has many ways of conveying information and as much of that as possible should be preserved for an interview if possible. A good transcription includes both the spoken words as well as the emphasis in sentences, intonations, pauses and preferably also body language. A good transcription also includes both manifest level data, that is the actual meaning of a sentence as well as latent level data, that is the interpretation of the sentence in a context (Hancock, 1998). As an example latent data would identify the difference between sincerity and irony, where manifest data would not. Transcriptions in this thesis only include the spoken word on a manifest level.

Once data is transcribed the content the data needs to be coded and classified, that means labelling each piece of information so causality, differences and similarities can be recognised. A method for this is content analysis, which is a multistep tool to decode transcripts. Then the data is rearranged into categories for major and minor trends in a thematisation step in order present the data in a way that lets it shed light on, and explain, the studied case and the phenomena from various angles (Hancock, 1998). The thematisation of this thesis uses only major categories. The trends can be chosen either in beforehand or be allowed to evolve during the thematisation process. In this thesis the trends were chosen in beforehand to answer the research questions and take the thesis scope and delimitations into consideration, this means only data from the interview that adds to answering the research questions or that contribute with information to other parts of this thesis methodology was collected during the thematisation. Data collection for qualitative analysis is a time consuming task for which the sample size often is smaller than for quantitative analysis (Hancock, 1998), in this study seven interviews was conducted.

2.4.3 Limitations in the qualitative analysis method

Performing a full qualitative analysis is far beyond the scope of this thesis so simplifications in the case study methodology presented by Baxter and Jack (2008) were done to fit the scope of this study. Simplifications such as; no pilot interview; no repetitive interviews; little or no feed back with interviewees after interviews; no extensive analysis for data saturation; no bias analysis; simpler form of transcribation and thematisation. A full-blown case study might have looked further into how opinions and attitudes about these parameters are formed and how they co-vary with their surrounding. While this simplified form lack validity and reliability to stand on its own it is the authors belief that it will be suffice within the scope as complement to existing literature and other data collected as well as it will enrich the other findings of the thesis. It is stressed that the findings from the interviews is only indications and not conclusive results, these indications are not valid on their own.

2.4.4 COREQ checklist

An issue with qualitative analysis, due to its very nature of emphasising on the context while trying to describe complex social interactions and phenomena, is that there is seldom one standardised method and this causes problems with reproducibility of the study. A checklist created by Tong. et al. (2007) aims to enhance transparency and completeness in data for qualitative studies by promoting explicitness in reporting data from interviews. Tong et al. (2007) hope that this checklist will help to improve comprehensiveness and credibility of qualitative interview data. Documentation of the qualitative study has been done in accordance with COREQ checklist; the checklist is presented in Appendix VIII and Appendix IX.

2.4.5 Local interviews

Four selected people from the village of Gwata was asked to participate in a semi-structured interview about most important system services, most severe pressure and threats to the forest and also asked about what amount of system services the forests can provide today. The interviews were conducted in Swahili with two translators and interviews took about 20 minutes each. The interviews were not audio recorded because of difficulties with transcribing them in Swahili but one of the translators took notes while the second translator asked the interview questions, the data was transcribed on a manifest level. The transcription was then thematised into major categories. Before the interviews a two hours preparatory meeting was held with the translators to describe the study and what type of information was sought in the interviews. Questions were asked with the goal to gain insight about system services and threats in the two forests, both today, historically and possible future development. Questions about the human demand on the forests were also asked. For more information on how the interviews were conducted see the COREQ checklist of the local interviews in Appendix IX.

Questions used in interviews with local people[1]
Q1: What condition are the two forests in (SUA forest and public land forest)? Which, if any, are the differences?
Q1: What services do the forest provide today?
Q3: Describe a definition for a forest
Q4: When would you stop going to this forest (the one close by)? Which products and services would have to disappear for you to find a new forest?
Q3: What kind of products and services would you like to have available/extract from the forest in order to fulfil your livelihood?
Q4: In what amount?
Q5: If you could, would you like to extract more/less/same and if so, which products/services?
Q6: Do you feel that the SUA forest benefits you, if so in what way?
If the answer is more/less in Q3
Q7: What reasons are keeping you from extracting the amount that you would like?
Q8: Has the services and products available in the forest changed over time?
Q9: Which services are the absolutely most important from the forest?
Q10: In what way has the land surrounded Gwata and Mazizi been used historically?
Q11: What is the biggest threat to your forest?
Q12: Who is taking decisions about what people that can use and extract resources from the forest?
Q13: What are the system services for each of the top 10 tree species?
Q14: What is the purpose of the SUA forest?

2.4.6 Researchers interviews

The researcher interviews with three researchers were conducted in the researchers' offices, they were in English, done individually and based on a series of open-ended questions. An interview lasted for about 30-45 minutes and the interviews were audio recorded, transcribed on a manifest level and thematised into major categories. Questions were asked with the goal to gain insight about system services and threats in the two forests, both today, historically and possible future development. Questions about the human demand on the forests and questions concerning the scenario development were also asked. For more information on how the interviews were conducted see the COREQ checklist of the interviews in Appendix VIII.

Questions used in interview with researchers:[2]
Q1: What is the present over-all condition of the two forests?
Q2: Which ecosystem and system services are the two forests providing today?
Q3: What are, if any, the differences in ecosystem and system services from the two forests?
Q4: Are there any services from the forests that are available but un-used? If so, which are they?
Q5: Which types of pressures are the two forests exposed to? Similarities, differences?
Q6: Are there any differences or similarities you would like to add on top of these?
Q7: Have the ecosystem and system service portfolio for each forest changes over time? In what way?
Q8: Which are the future external pressures on the forests?
Q9: When does a forest stop being a forest, with respect to system services? What is the minimum requirement for system services according to your opinion?
Q10: The tree spices distribution is different for the two forests, why? What are the implications of this?
Q11: What are the system services for each of the top 10 tree species?
Q12: Is there a linkage between soil carbon and system services? Please elaborate.

[1] The protected forest is named as SUA forest and the unprotected forest as the public land forest in the interviews.
[2] The protected forest is named as SUA forest and the unprotected forest as the public land forest in the interviews.

Q13: What is the purpose of the SUA forest?
Q14: Is there any intrinsic value in maintaining a forest? Which are they?
Q15: What is your view on the condition of the forests?
Q16: If natural and intact forest is the starting position, how long time will it take to go from that to a forest just in the border of not being classified as a forest anymore? Is it possible for that forest to recover to a SFM forest and how long time would that take?
Definition SFM: "Sustainable forest management, as a dynamic and evolving concept, aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations."
Q17: What service would disappear each year at the above-mentioned time scale?

2.5 System services

The fourth element of SFM is characterize as productive functions of forest resources which is an element that offer opportunity of income for a number of people and societies (FAO, 2010). An example of this is found in the surrounded area of this study where 81 % of the people in Maseya and Gwata (villages located in adjacent to Kitulangalo forest reserve) make their living on agriculture and charcoal extraction (Malimbwi et al., Not published). The most important system services for the local people were identified during the interviews and then utilized when evaluating how well each forest systems provided these services. The interviews needed to be preformed before evaluating the forest since the result acted as a basis for that evaluation. The reader should pay attention to the fact that local system services were highlighted, not global system services. The global services to be evaluated were already determined beforehand, as biodiversity and carbon stock, even if these services may benefit the local people as well. Specific local system services that could be connected to suitable tree species, according to the literature study in theory chapter 3.3, were quantified. A limitation in DBH for those species was also established based on the result from the interviews and the literature study. For example all trees that represented suitable species for charcoal making (listed in Table 4) and that complied with the DBH limit for charcoal were summarised and presented as total biomass in a diagram. The same procedure was done for all local system services that could be connected to tree species and therefore be quantified.

3 Literature review / Findings from previous studies

This chapter describes present findings from previous studies for carbon stock, biodiversity and important system services for the people that live around Kitulangalo area.

3.1 Carbon stock from previous studies

A previous study preformed for Miombo woodlands in general has concluded an average carbon stock of 28 tonne carbon per hectare (tC/ha)[3] in AGB and BGB, where different calculation methods for above-ground biomass and carbon storage were weighted together. The study excluded trees below a DBH of 10 cm and biomass in below-ground, litter and deadwood (Shirima et al., 2011). Estimates of carbon stock for areas in the protected forest and for the unprotected forest have also been made previously by Zahabu (2008). The plots for Zahabu's study were placed at the exact same location as this study for the protected forest and close to the plots for the unprotected forest. His plots for that forest system were placed next to Gwata village close to the highway between Morogoro and Dar es Salaam. The two areas are under the same management system with open-accessed public land, although the placement of Zahabu's plots is different from this study. His study includes biomass in above-ground, below-ground (estimated mathematically with a root to shoot ratio from the above-ground), litter and dead wood. Soil organic carbon is also included and small trees with a DBH above 1 cm (Zahabu, 2008).

The historical carbon content are presented in Table 1 and as can be seen a carbon increment from 2005 to 2007 took place in the protected forest. Followed by a decrease from 2007 to 2008 (Zahabu, 2008). For the unprotected forest it can be noticed a major decrease in carbon content from 2000 to 2006, which according to Zahabu was due to charcoal harvesting. Almost all trees were removed with the purpose to use them for charcoal in some of the areas where the plots where located during his study. After 2006 an increase in carbon stock raised and the reason could be due to rampant regeneration after harvesting and a decrease in preferred species for charcoal making, leaving the unwanted species left to grow and increase in biomass (Zahabu, 2008).

Table 1; Historical values for carbon content in the studied area and from Miombo in general. Values for the protected forest are presented as a confidence interval with p=0.10

Year	Carbon (tC/ha) in the protected forest(Zahabu, 2008)[4]	Carbon (tC/ha) in the unprotected forest (Zahabu, 2008)	Miombo woodlands (Shirima et al., 2011)
2000		12	
2005	18±5	4,3	
2006	20±4	2,8	
2007	23±5	4,0	
2008	21±4	3,5	
2011			28

[3] Found in the litterture as 23 tC/ha for ABG but is here presented with an added BGB when using the root to shoot ratio of 0,2.

[4] The protected forest is named as KSUATRF in Zahabu's thesis and the unprotected forest is named as Kitulangalo area. The biomass is exclusively presented for the unprotected forest so the numbers in the table are calculated as 50 % of these as that is the standard carbon content in biomass.

Several prior studies have investigated the carbon levels in soil in Miombo Woodlands. Desanker and Walker (2004) conducted a study in Malawi on land use and its impact on soil carbon. They use an elemental analyser to quantify the carbon content. Desanker and Walker (2004) suggest that a carbon stock in soil for Miombo Woodlands in Malawi is (for 0-150cm depth) 80 tC/ha. Furthermore the authors suggests that almost 30 % of the carbon in soil from 0 to 150 cm is found in the top 10 cm. Nord (2008) conducted a study in Kitulangalo where the author studied soil properties under different land uses also by using the Walkley-Black method for carbon estimation. Msanya (1995) did research on soil properties in Kitulangalo forest reserve and Campbell (1996) composed research for average values for Miombo woodlands in Africa, both using the Walkley-black method. Their findings are presented in Table 3 but the denotations have been altered, original titles for each forest is found in Table 2.

Table 2; Original denotations and new denotations for historical reference data for organic carbon

Original denotation for forest	New denotation	Reference
Miombo Woodlands	Protected forest, Malawi	(Walker and Desanker, 2004)
Miombo Woodlands	Protected forest, Africa	(Campbell, 1996)
Kitulangalo forest reserve	Protected forest, Kitulangalo	(Msanya et al., 1995)
Degraded forest	Unprotected forest, Kitulangalo	(Nord, 2008)
Regenerating degraded forest	Protected forest, Kitulangalo	(Nord, 2008)

content presented in Table 3

Table 3; Historical values for organic carbon content in Miombo woodlands soil in mass percentage with depth range and soil texture from 1995, 1996, 2004 and 2008. Standard deviation is presented for some of the values

Name, Location	Organic carbon content [%]	Range	Soil Texture	Reference
Protected forest, Malawi	2,3[5]	0-10cm	Sandy loam, sandy clay loam[6]	(Walker and Desanker, 2004)
S.D.	1,1			
Protected forest, Africa	1,4	0-20cm	Loamy sand, sandy loam, sandy clay loam	(Campbell, 1996)
S.D.	0,9			
Protected forest, Kitulangalo	0,41-3,1	”topsoil”	Sandy loam	(Msanya et al., 1995)
Unprotected, Kitulangalo	1,4	0-5cm	Sandy clay	(Nord, 2008)
Confidence interval (p=0.05)	0,41[7]			
Protected forest, Kitulangalo	1,5	0-5cm	Sandy clay	(Nord, 2008)
Confidence interval (p=0.05)	0,36[3]			

[5] This study used an elemental analyser which quantifies all carbon, not only organic carbon.

[6] Modified from Walker and Desanker 2004 - Original data: clay+silt content = 46 % with S.D. 16,8 %

[7] Modified from Nord 2008 – Original data: Graph

3.2 Biodiversity from previous studies

Studies of the species composition has previously been done by Malimbwi et. Al (2001) and Zahabu (2008), who located their plots at the same place as this study for the protected forest and in similar areas for the unprotected forest (see section 3.1. and 3.3.1 for a detailed description of the placement). In 2001 a number of 48 and 44 different species were found in the protected and the unprotected forest[8] respectively, but that number changed remarkably until 2008 where a total number of 56 and 21 different species were found respectively (Zahabu, 2008)[9]. At that time the protected forest was mostly dominated by *Julbernadia globiflora, Brachystegia boehmi, Acacia nigrescens* and *Sclerocarya birrea* and the distribution is visually presented in the figure below (Figure 3).

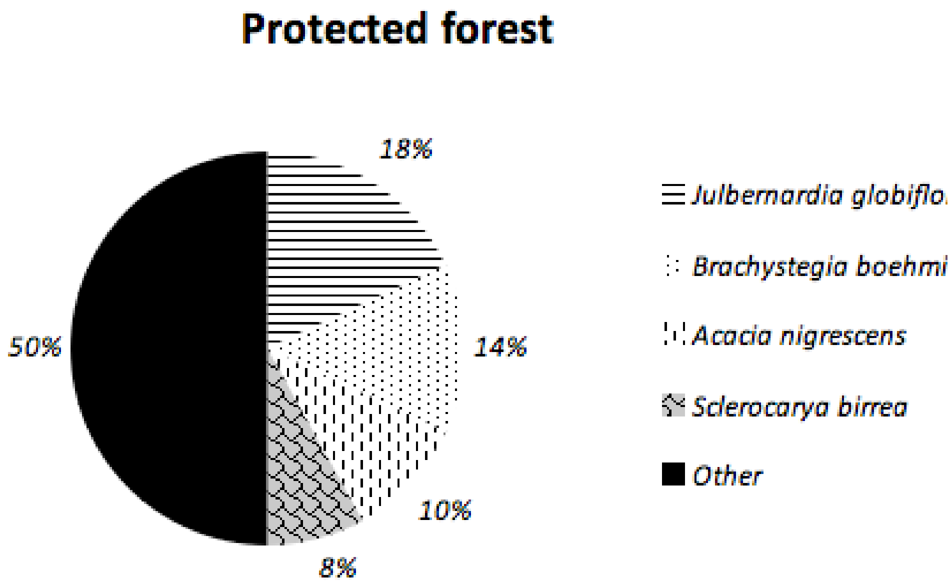


Figure 3; Historical values for tree species dominance in terms of biomass content in the protected forest (Zahabu, 2008)

A remarkably high alteration was found in the unprotected forest, which was highly dominated by *Xeroderis stuhlmanii,* which represent 66 % of all trees (Figure 4). This pronounced dominance by a single species implies degradation and loss in biodiversity. Zahabu (2008) suggests that this species may be intentionally left for timber production since *Xeroderis stuhlmanii* is suitable for that purpose.

8 Named as the public land in Malimbwi et al. (2001)

9 The protected forest is named as SUA Training Forest Reserve and the unprotected as general land in Zahabu's thesis.

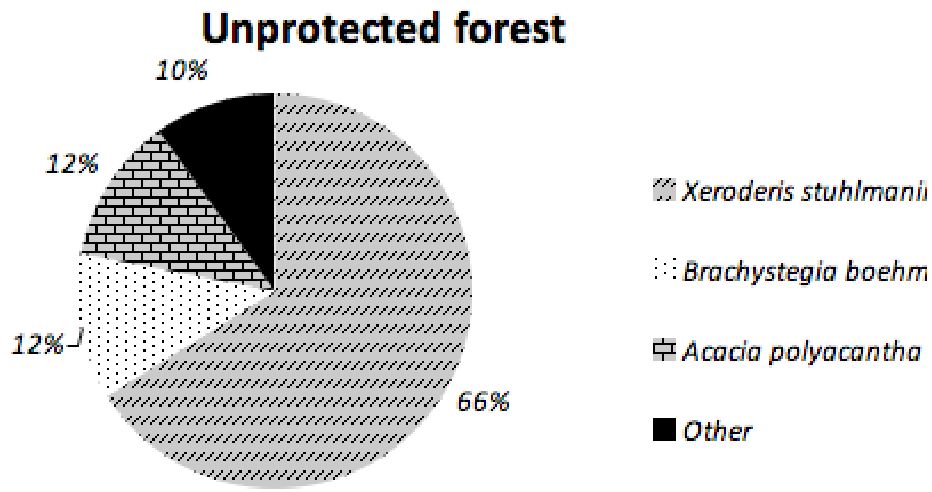


Figure 4; Historical values for tree species dominance in terms of biomass content for the unprotected land[10] (Zahabu, 2008)

3.3 System services from previous studies

The method chapter highlighted the importance of system services as a source of income for a number of people and societies. Professor Y. Ngaga (personal communication, August 15, 2012) distinguish a difference in major source of income between two villages in Kitulangalo area i.e. Maseyu and Gwata. Most people of Maseyu make there living on charcoal whereas people in Gwata is more highly dependent on agriculture. The education level of Maseya and Gwata is low; most people have an education level of 4-7 years in school while 40 % have no education at all. The low education level creates a dependence on agriculture and charcoal making to generate income (Malimbwi et al., Not published). The plots for this study were located close to these villages the villagers are assumed to have similar education background and source of income. In 2005 the population of Gwata was 2840, the number of households was 368 in 2005 and just above 200 in 1995, which is equal to an increase in households of around 80 % during that time period (Nduwamungu et al., 2009). However, a study that performed interviews with the people living in villages around Kitulangalo showed that 60 % of the interviewees were not born in their respective village. The study implies a high immigration rate to the area (Malimbwi et al., Not published). Other important services from the forest are building poles, timber and firewood.

3.3.1 Charcoal

Charcoal is often produced in the unprotected forest that surrounds the villages Maseya and Gwata, however 80 % of the people in Malimbwi et al. (Not published) study stated that the distance to where they go to produce charcoal has increased due to tree scarcity in the area. Therefore they have to constantly move the production site. Malimbwi et al.'s study (Not published) also stated that most people in the villages select species suitable for charcoal making and a summery of those are found in Table 4. Among suitable species, two species are most highly preferable by the villages i.e. *Julbernardia globiflora* and *Brachystegia boehmii.* A significantly higher grade, at least twice the amount, of the suitable species was found in the protected forest compared to the unprotected forest, according to Malimbwi et al. (2001). The

[10] Named as Kitulangalo General Land in Zahabu's thesis

plots for that study were located at the exact same place for the protected forest as in this study and in the public land of the two villages that border the Kitulangalo SUA Traning Reserve for the unprotected forest case. A tendency of lower levels of biomass for tree species suitable for charcoal making was found close to the roadside and the levels rose further into the forest. After a distance of 15 km from the roadside the levels started to decrease again. The study's authors highlight the phenomena as indications that harvesting occurs for other purposes than for charcoal making e.g. to use the trees for building poles and firewood by the people in the small villages that surrounds the area (Malimbwi et al., 2001). There is a demand of charcoal for both domestic and external use but the price of selling charcoal along the highway roadside is 40 % higher compared to selling charcoal to villagers, making it more profitable to sell charcoal for external use (Malimbwi et al., Not published). In 2005 the sell price at the road side was 133 % higher than at the production site and the authors concluded that the highway have resulted in an increased charcoal production in the area (Nduwamungu et al., 2009). When harvesting trees for charcoal making a limit in DBH of above 10 cm is recommended (Malimbwi and Mugasha, 2001).

3.3.2 Building poles

Building poles are used as construction material for rural housing and as supporting construction when building concrete structures (Makonda, personal communication, December 8, 2012). The most preferable species for building poles is *Spirostachys Africana* due to its termite-resistance. Consequently this species are subjected to high pressure in the past which might have reduced its accessibility in Kitulangalo forest reserve (Luoga et al., 2000). Previous studies made in Miombo woodlands have listed species suitable for building poles and a summery of those are found in Table 4 (Malimbwi and Mugasha, 2000) cited in (Malimbwi and Mugasha, 2001) and generally a limit of 10 cm DBH is applied when harvesting these trees.

3.3.3 Timber

The village people use timber for sawing of planks and most sawmills require timber logs (Makonda, personal communication, December 8, 2012). According to Maliondo's study in 2005 most preferable species for commercial timber production in Miombo woodlands are: *P. angolensis, Afzelia quanzensis* and *Brachylaena huillensis*. However the large trees of these species are often depleted, making other species as: *Brachystegia spp., Julbenardia spp., Isoberlinial spp.* And *Sterculia spp.* To be used as the most preferred ones instead. They can be used for commercial timber production, railway sleepers and plywood production (Maliondo et al., 2005). Malimbwi and Mugashi (2000) cited in Malimbwi and Mugashi (2001) have listed species suitable for timber production and an overview of those species together with the most preferred ones are listed in Table 4. Malimbwi and Mugashi (2000) cited in Malimbwi and Mugashi (2001) recommend a DBH of above 60 cm to get saleable timber although a DBH of above 40 cm was recommended for small size trees such as *Xeroderris stuhlmannii*. Malimbwi and Mugashi (2001) show that the protected forest has little to offer when it comes to timber with only 5 species that can reach the recommendation of DBH > 60 cm. Nduwamungu et al. (2009) concluded that the close proximity to the highway have lead to an increase in timer extraction of the forest close to the highway.

3.3.4 Firewood

Another use of forest product is for firewood/wood fuel. Woody products used for this purpose are normally dead branches, naturally dying trees and unused materials from trees that are harvested for other reasons, although collection of live wood occur as the live material extend the burn time of the fuel (Luoga et al., 2000).

3.3.5 Summery of species and tree sizes connected to system services

A summery of all species most preferable and suitable for the system services charcoal, building poles and timber is found in the table below. The table is a summery of the references found in the text above.

Table 4; A summary of most preferable species (light gray shading) and suitable species (gray shading) for system services; charcoal making, building poles and timber production. Presented in both local name and latin name

Local name	Latin name	Charcoal	Building poles	Timber
Mhungilo	*Lannea schimperi*			
Mkambala	*Acacia nigrescens*			
Mgama	*Mimusops kummel*			
Mkongowe	*Acacia gerrardii*			
Mnhondolo	*Jurbernadia globiflora*			
Mlama mweusi	*Combretum molle*			
Mfumbili	*Lonchocarpus capassa*			
Msisimizi	*Albizia harvey*			
Mgovu	*Pteleopsis myrtifolia*			
Mnyenye	*Xeroderris stuhrmanii*			
Mtanga	*Terminanalia mollis*			
Kifunganyumbu	*Acacia nilotica*			
Msolo	*Pseudolachnostylis maprouneifolia*			
Mtogo	*Diplorhynchus condylocarpon*			
Mlama mwekundu	*Combretum zeyheri*			
Mguluka	*Boscia salicifolia*			
Kisasa	*Acacia goetzei subsp. Goetzei*			
Myombo	*Brachystegia boehmii*			
Mharaka	*Spirostachys africana*			
Mlama mwekundu	*C. zeyheri*			
Mlama ng'ombe	*C. adonogonia*			
Mkongo	*Afzelia quanzensis*			
Mninga	*Pterocarpus angolensis*			
Mpingo	*Dalbergia melanoxylon*			
Mninga maji	*Pterocarpus rotundifolius*			
Mpilipili	*Sorindeia madagascariensis*			
Mkurungo	*Brachystegia spp.*			

System services are connected not only to preferable tree species but also to tree DBH diameter in Table 5 (Makonda, 2012) thus both criteria; right species and right size need to be fulfilled to give the sought after system service.

Table 5; System services connected to tree size diameter at breast height (non-specific tree species)

Tree size [DBH]	System services
<10 cm	None
10-19 cm	Charcoal
	Building poles
20-29 cm	Charcoal
	Building poles
>=30cm	Charcoal
	Building poles
	Timber

4 Result

The result from the field assessment is presented as carbon stock in above- and below-ground biomass, carbon content in soil, number of trees per DBH class, mean height of trees per DBH class and biomass per tree in the different DBH classes and carbon content in soil. Biodiversity are presented as the ten most common species and species found in each forest. Results from the interviews are presented as a list of most important system services for a forest, system services connected to tree size and major pressures and threats to each forest. Tree species that fulfilled the criteria for most important system service and DBH class were presented as total biomass in a diagram.

4.1 Carbon stock

The carbon stock in AGB and BGB was higher in the unprotected forest than in the protected, but the difference was of small magnitude and represented a difference of 1,6 tC/ha. The number of trees was remarkably higher in the unprotected forest with 685 compared to 574 in the protected forest but the average height was greater in the protected forest. Number of stumps was considerably higher in the unprotected forest that in the other forest case as seen in Table 6.

Table 6; Field assessment data for protected and unprotected forests. Carbon stock in AGB, additional BGB calculated with root to shoot ratio (both AGB and BGB with confidence interval of 95 %), total number of trees counted in each forest system with a DBH above or equal to 10 cm, mean DBH for each forest system, mean height for each forest system and total number of stumps counted in each forest system

Location	Protected forest	Unprotected forest
Confidence interval of carbon in above-ground biomass (tC/ha)	19,6±4,18	20,9±4,19
Added BGB (Root to shot ratio of 0,2)	23,5±5,02	25,1±5,03
Total nr of trees	574	685
Mean DBH (cm)	20	21
Mean height (m)	7,7	6,9
Nr of stumps	3	111

Number of trees was greatest in the smallest DBH class of 10-19 cm for both forest systems and the mean height was larger in all DBH classes for the protected forest compared to the unprotected (Figure 5).

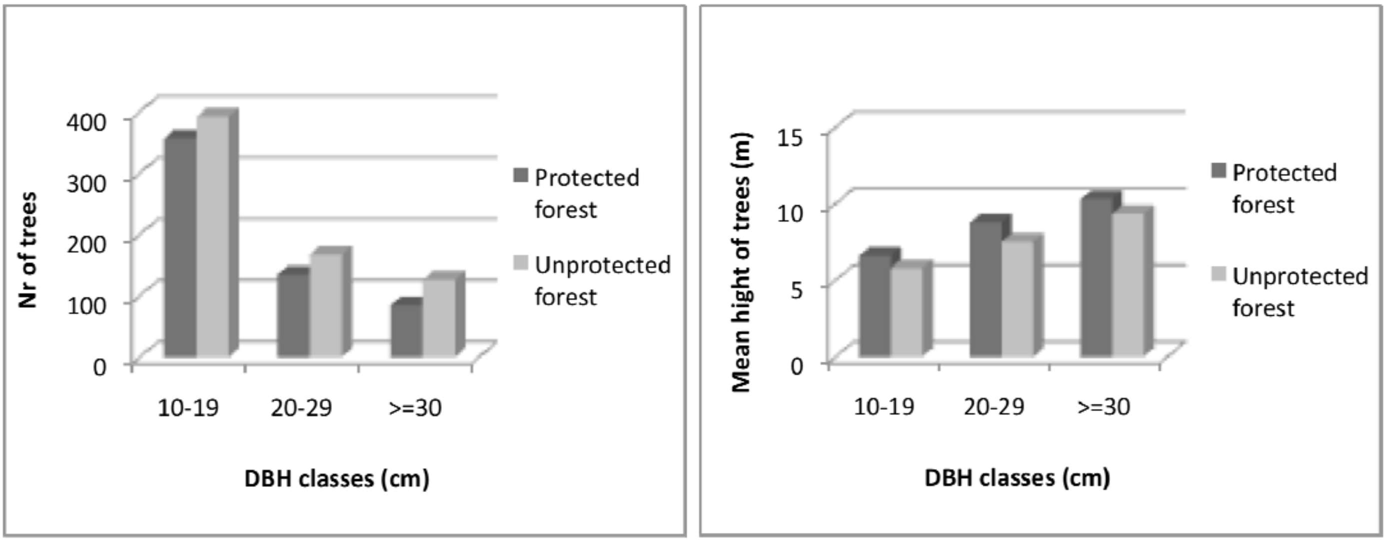


Figure 5; To the left: Total number of trees in the two forest systems divided into different DBH classes. To the right: Mean height for the two forest systems divided into DBH classes.

The protected forest stored larger amount of biomass in each tree compared with the unprotected forest, as can be seen in Figure 6.

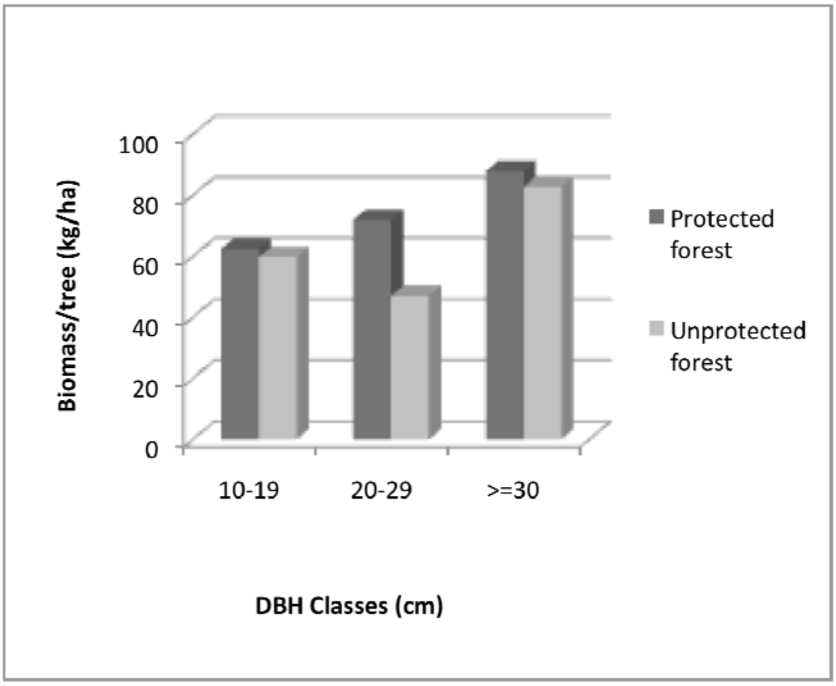


Figure 6; Biomass per tree for different DBH classes for the two forest systems.

The soil organic carbon stock was higher in the protected forest than in the unprotected forest with 1,9 percent and 1,6 percent respectively as seen in Table 7. The soil texture is similar in both forests but the protected forest had more silt than the unprotected forest but lower amount of sand. The clay content was roughly similar in both forests. The proportion clay, silt, sand results in a sandy loam, sandy clay loam for both the protected forest and the unprotected forest.

Table 7; Organic carbon content for top soil and soil texture analysis, silt and sand for protected and unprotected forest. Including standard deviation (S.D.)

Location	Soil organic carbon [%]	Range	Clay [%]	Silt [%]	Sand [%]
Protected forest	1,9	0-10cm	21	8,1	71
S.D.	0,60		5,3	2,6	6,3
Unprotected forest	1,6	0-10cm	21	7,2	72
S.D	0,54		6,8	2,5	7,4

4.1.1 Comparison between two different calculation models for above-ground biomass

Equations for above-ground biomass may create uncertainty in the result as mentioned in the method chapter 2.2.1. Therefore the result from the carbon stock was calculated with the equation specially developed for Kitulangalo (equation 1) and compared with an equation developed for dry tropical forest (equation 2). The result is presented in Figure 7 and Figure 8 as the total carbon stock at each plot for both forests. The values follow the same magnitude in most cases but equation 2 had more often a slightly higher value than equation 1. This number was greater in the magnitude of 6-9 tC/ha in plot number 58 and 59. These plots included trees with a large average DBH and a low average height (see Appendix III). The carbon stock calculated with equation 1 was found to be higher than the values calculated with equation 2 in some of the cases. In plot number 18, 20, 21, 23, 31 and 49 the values could vary up to 6-10 tC/ha. As can be seen in Appendix III these six plots have an average DBH close to the average for the whole forest case and a relatively high height.

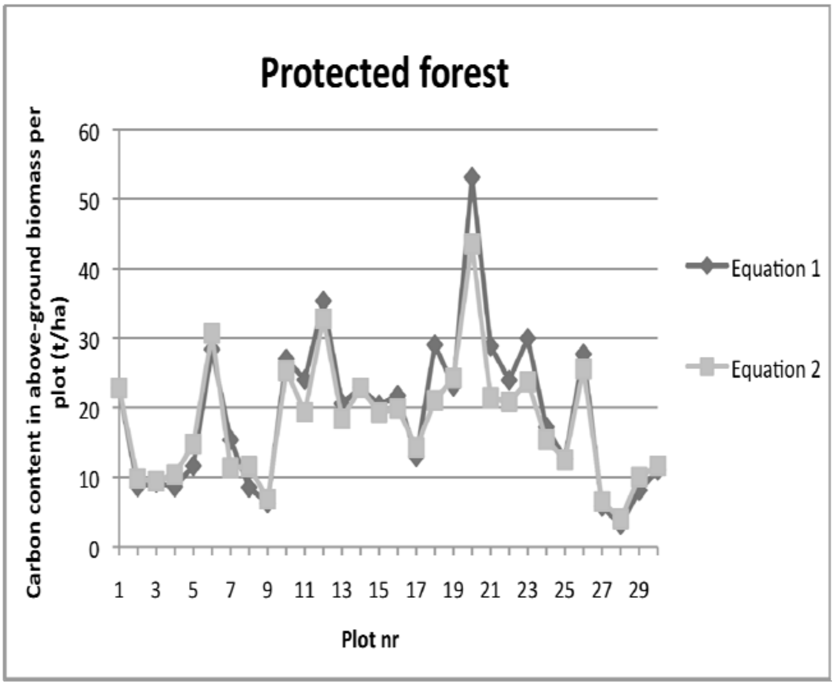


Figure 7; Carbon content in above-ground biomass for each plot in the protected forest calculated with two different equations

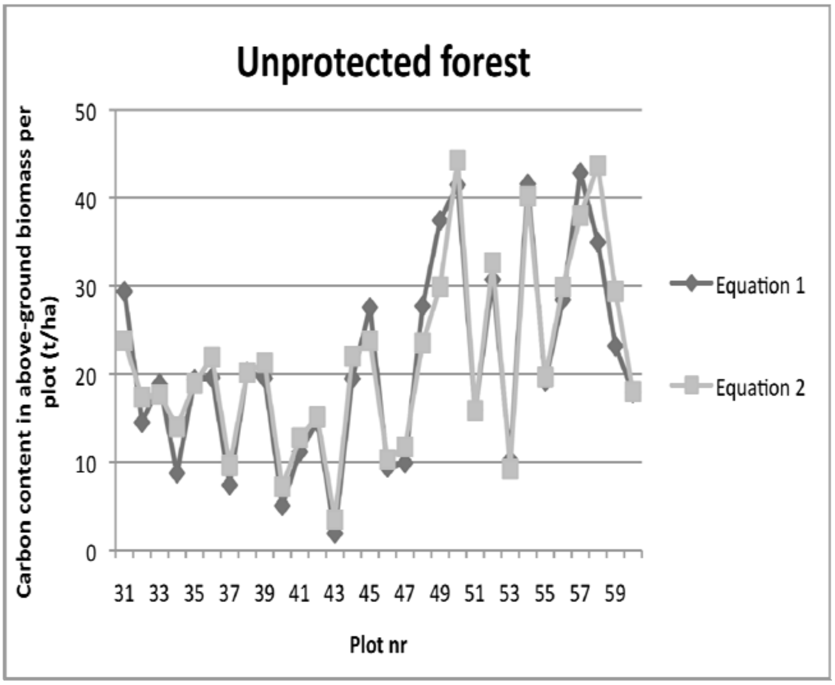


Figure 8; Carbon content in above-ground biomass for each plot in the unprotected forest calculated with two different equations

4.2 Biodiversity

The total number of species was lower in the protected forest compared to the unprotected forest with 49 and 50 species respectively (see Table 8), but a higher dominance of a few species was distinguish in the protected forest. In fact the summarisation of the ten most common tree species covered a higher total percentage of trees, equal to 68 percent in protected forest and 55 percent in unprotected forest, see Figure 9 and Figure 10. General family species characteristic for Miombo woodlands are; *Brachystegia, Julbernardia and Isoberlinia. Julbernardia globiflora* was found to be the second most common tree in the protected forest but not even represented among the top ten in the unprotected forest. *Brachystegia boehmii* was found in both forest types but was slightly more common in the protected forest with 5 percent and 4 percent in the unprotected. *Isoberlinia* was not found in any of the forests. *Combretum molle* was the most common species in both forests but represented to a higher frequency in the protected forest.

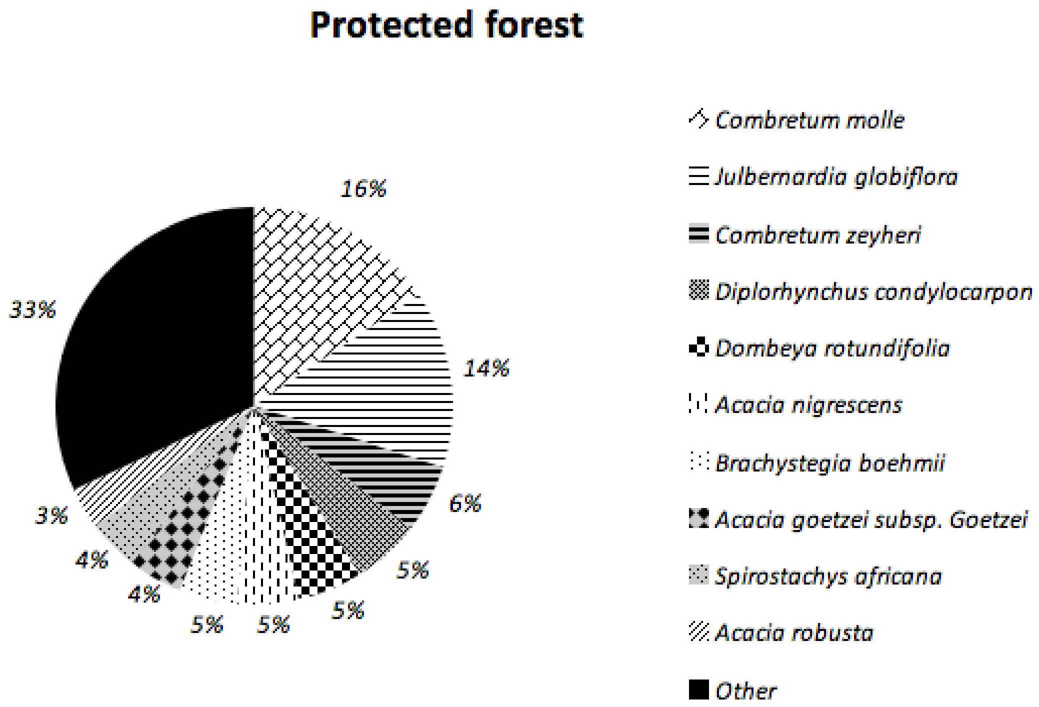


Figure 9; Frequency of the ten most common species in the protected forest, with a total percentage of 68

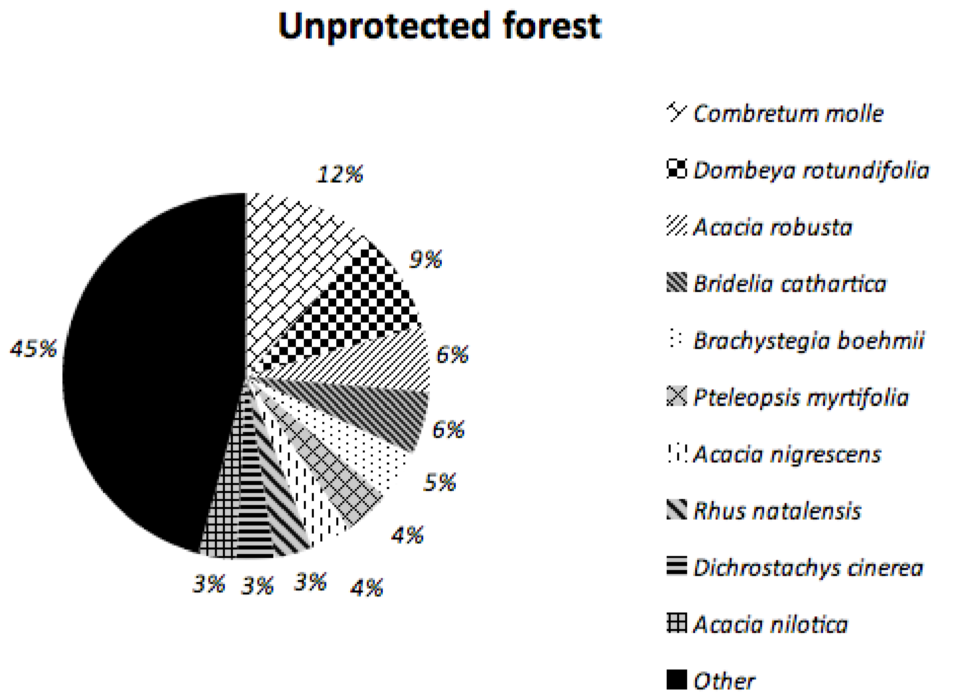


Figure 10; Frequency of the ten most common species in the unprotected forest, with a total percentage of 55

Today's result and historical result in species composition of the most common species are summarised in Table 8 to get a clear overview for later evaluation if a loss in biodiversity has occurred. As can be observed in the overview the most common species in both forest cases (*Combretum molle*) was not even presented among the most common species in historical findings. *Julbernardia globiflora, Brachystegia boehmii* and *Acacia nigrescens* were presented among the most common species in historical findings in the protected forest but to a higher percentage than today's result. *Sclerocarya birrea* was represented to a frequency of 8 percent for the same forest system in historical findings and today not even presented among the top ten species with just a frequency of 1,4 percent (see Table 8 and Appendix IV).

For the unprotected forest on the other hand *Xeroderris stuhlmannii* was the most dominant species in prior study where it represented 66 percent of the total biomass content. Today this species was not even presented among the top ten most common species and the same was the case with *Acacia polyacantha*. *Brachystegia boehmii* was present as 12 % in 2008 and as 4 % today.

Table 8; Frequency of the most common tree species in protected and unprotected forest from 2008 and 2012 presented with frequency in percentage

Local name	Botanic name	Frequency Protected forest (%)		Frequency Unprotected forest (%)	
		(Zahabu, 2008)	2012	(Zahabu, 2008)	2012
Mhondolo	Julbernadia globiflora	18	14	-	-
Myombo	Brachystegia boehmii	14	5	12	4
Mkambala	Acacia nigrescens	10	5	-	4
Mng'ongo	Sclerocarya birrea	8	-	-	-
Mnyenye	Xeroderis stuhlmanii	-	-	66	-
Muwindi	Acacia polyacantha	-	-	12	-
Mlama mweusi	Combretum molle	-	16	-	12
Mlama mwekundu	Combretum zeyheri	-	6	-	-
Mtogo	Diplorhynchus condylocarpon	-	6	-	-
Msoto	Dombeya rotundifolia	-	5	-	9
Kisasa	Acacia goetzei subsp. Goetzei	-	4	-	-
Mcharaka	Spirostachys africana	-	4	-	-
Mkongowe	Acacia robusta	-	3	-	6
Msinzira	Bridelia cathartica	-	-	-	6
Mngoji	Pteleopsis myrtifolia	-	-	-	4

Msempele	Rhus natalensis	-	-	-	3
Kikulagembe	Dichrostachys cinerea	-	-	-	3
Kifunganyumbu	Acacia nilotica	-	-	-	-
Other (%)		50	32	10	46
Total number of all species		(48*) 56	50	(44*) 21	54

* (Malimbwi and Mugasha, 2001)

4.3 Interviews

Each of the seven interviews generated a unique view of the two forests examined. The entire transcripts from the interviews are not presented; only findings from the thematisation are shown in these results. The information in the thematisation was rearranged to reveal general trends and shed light on, and explain, the thesis research questions and how they are connected to the studied case. This means information from interviews, which does not aid to answer the research questions, is not presented, this also includes some of the questions asked during the interviews which later in the project process was excluded from the scope. It is stressed that the findings from the interviews is only indications and not conclusive results, these indications are not valid on their own (see 2.4.1). The results are presented for each trend from the thematisation with a general explanation for each trend, a list of most important parameter and with aid from quotations from the interviews.

4.3.1 Thematisation of interviews

The two forests are under two different forest management regimes wherefore the interviewees were asked to specify similarities and differences between the forests.

Trend 1: General condition

A majority of the interviewees (though not all) were of the opinion that the protected forest was in better condition than the unprotected forest in terms of system services and in withstanding threats. A minority of the interviewees claimed both forests were in a good condition. A common opinion was that the unprotected forest has degraded over time, that it used to be in a better condition and the consequences are seen today where it is getting harder for local people to find and extract the resources they want because useful species have been extinct and because the big trees have been felled, both local people and researchers talk of resource depletion.

"Protected forest is in a good condition, the unprotected forest is degraded" – Local 2

"There are not enough resources in the unprotected forest" –Local 1

"/…/ 10 years ago you could find some species that today are extince /…/ Some tree species are extince in both places [protected and unprotected forest] mostly due to human pressure. As for example a tree species used to produce timber." – Researcher 3

Trend 2: Important system services and pressures for the two forests
The protected forest was restricted for most types of resource extraction; therefore the most important system services were not focused on physical forest resources. There was a discrepancy between the researchers and the local people in terms of most important system services. The local people identified fewer important system services than the researchers from the protected forest; biodiversity conservation was not mentioned at all. The following services were stated as most important in the interviews for the protected forest.

"/…/ they [local people] do not think of oxygen and carbon sequestration, which is very important. They rather refer to charcoal and firewood" –Researcher 3

"There is a good carbon stock inside the protected forest compared to outside. Without measuring the tree you can see it." –Researcher 1

Most important system services for protected forest
- Carbon storage
- Biodiversity conservation

From the interviews it was indicated that the threats were believed to occur to a lesser extent in the protected forest than in the unprotected forest. Mainly due to the fact that there are patrolling guards in the protected forest preventing the threats mentioned. Major pressures and threats for the protected forest were the following.

"The unprotected forest is exposed to the same [pressures] as the protected forest, but more severe since it can be manipulated easily" –Researcher 3

Pressures and threats for the protected forest
- Encroachment
- Illegal collection of forest resources

The unprotected forest provides system services more focused on the local needs because the local people are allowed to extract resources there. There was a general belief, between researchers and local people alike, that the unprotected forest suffers from over extraction of system services. The local people identified problems with over-extraction but they also mentioned that if they would limit their own extraction it would not decrease the extraction rate because someone else would extract the resources instead. The researchers mentioned that the unprotected forest is systematically degrading, for example they suggested the most valued tree species for charcoal and building poles would not be found at all today due to extraction. Most important services that the unprotected forest provided, according to the interviews, were the following. When asked, the local people also stated that they would like to extract all of these services to a higher extent to meet their needs

Most important system services for the unprotected forest
- Timber
- Building poles
- Charcoal
- Firewood

Both local people and researchers implied that the unprotected forest was under much pressure from several threats. One of the biggest was the agricultural expansion and thus land-use change. The respondents suggested that this expansion of agriculture and most of the other threats were driven because of accessibility to the highway but also population growth, both from births and also from urbanisation. The interviewees identified that this area was very attractive for people to move into, because of the forest. Identified major pressures and threats to the unprotected forest are found below.

Major pressures and threats to the unprotected forest

- agricultural expansion
- frequently annual wildfires
- charcoal production
- shifting cultivation
- encroachment
- timber and building poles collection
- stone mining
- grazing

Trend 3: Drivers for external pressures

Two main external drivers were recognised to contribute substantially to the forest degradation mechanisms for these specific forest systems, both in the protected and unprotected forest. The drivers are accessibility issues from the close proximity to the Dar es Salaam highway and the high population increase, since this area is an attractive area for people to move to. The drivers are problematic not only because they are extensive but also because they are external, meaning the local people have very little possibilities to influence the future development. During the interviews it was clear that the over all opinion was that these two drivers intensified the pressure on the two forests considerably, though less on the protected forest due to the patrolling guards and protecting legislation. The two drivers are interlinked; the population growth is not only from birth rates but also because the accessibility makes the area attractive for immigration because it creates opportunity for employment and income generating activities from forest resource extraction. The accessibility driver has created a second demand on the forest, on top of extraction for domestic usage there is also extraction for commercial reasons, a differentiation recognised by both researchers and local people. Both researchers and local people rise doubts that a forest exposed to this much pressure can survive. It was expected that the unprotected forest would be deforested within ten years. The researchers questioned if it would be economically feasible to increase the level of protection needed to match the increasing pressure on the protected forest in the future, though it was made clear there is a lack of scientific data of such scenarios.

"The accessibility contributes in a large amount to the charcoal production since people making charcoal are attracted to areas where a lot of people are passing every day. /…/ It is likely that a lot of efforts will be need to protect such a forest" – Researcher 1

[on what amounts of resources local people want to extract] "varies according to the use, personal/domestic use or for selling." -Local 4

Important external drivers for this specific forests

- Forest accessibility from the close by Dar es Salaam highway
- Population increase in the area

4.4 System services

Most important local system services identified in the interviews that could be connected to tree species and DBH classes were: charcoal, building poles and timber. All trees that represented suitable species for those services (see Table 4) and that complied with the DBH limit for that service (accoding to Table 5) were summarised and presented as total biomass in Figure 11.

The protected forest had a higher potential in providing trees suitable for charcoal making and building poles while the unprotected forest had a higher potential of providing trees suitable for timber production.

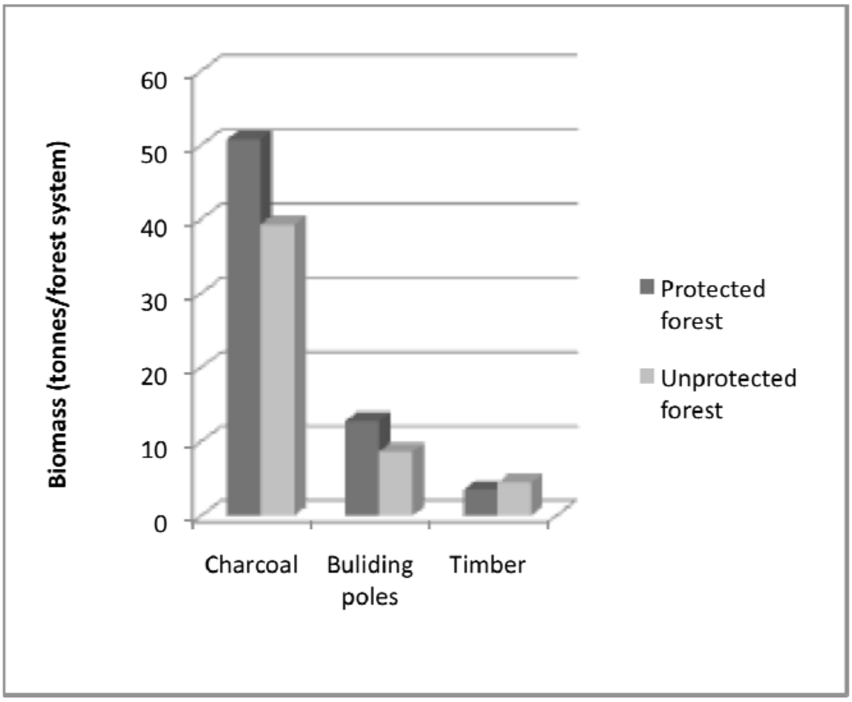


Figure 11; Total biomass stock of suitable species for charcoal making, building poles and timber for protected and unprotected forest. Based on suitable tree species for each system service and on recommended minimum limits for DBH for each system service

Figure 12 present the same result but with normalised values instead to clearer demonstrate the differences. The differences in percentage between the two forest cases to provide these system services were quite similar for charcoal and timber and slightly higher for building poles.

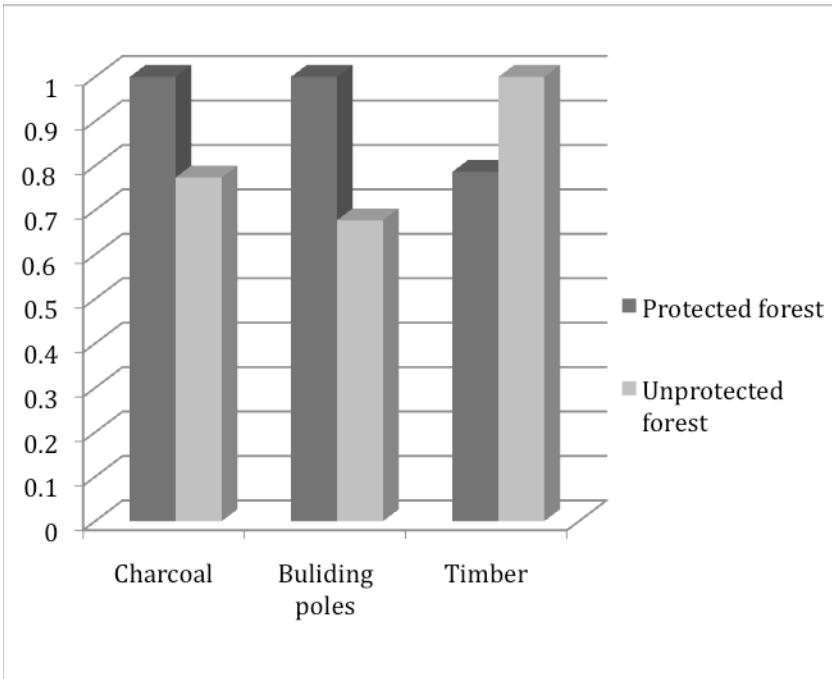


Figure 12; A normalised graph showing the difference of total biomass stock of trees that can provide trees suitable for providing the system services; charcoal making, building poles and timber in the protected and unprotected forest

Specific species that fulfilled the criteria for recommended DBH classes and most preferable species or suitable species for charcoal making, building poles and timber only species are summarised in Table 9. *Lannea schimperi, Mimusops kummel, Pteleopsis myrtifolia* and *Boscia salicifolia* are species that were suitable for charcoal but did not fulfil the DBH criteria in any of the two forests. A species listed among species suitable for building poles and not represented at all in any of the forest cases was *Spirostachys Africana* (see Table 9). The species with highest predominance for timber production in unprotected forest were *Peterocarpus* and *Pseudolach,* while protected forest was dominated by *Julbernardia globiflora* (for specific values see Appendix V-VII). A number of species were not even presented in any of the cases i.e. *Afzelia quanzensis, Pterocarpus rotundifolius, Isoberlinial spp. And Brachylaena huillensis. Pterocarpus angolensis* was found to a higher grade in the unprotected forest as can be seen in the table below.

Table 9; Trees that fulfilled the criteria for recommended DBH classes (according to Table 5) and most preferable species (light gray shading) or suitable species (gray shading) for the system services; charcoal making, building poles and timber production. X corresponds to present trees that fulfilled the criteria and – means that there is no tree available that fulfilled the criteria

Local name	Latin name	Charcoal		Building poles		Timber	
		Protected forest	Unprotected forest	Protected forest	Unprotected forest	Protected forest	Unprotected forest
Mhungilo	*Lannea schimperi*	-	-				
Mkambala	*Acacia nigrescens*	X	X				
Mgama	*Mimusops kummel*	-	-				
Mkongowe	*Acacia gerrardii*	X	X				
Mhondolo	*Jurbernadia globiflora*	X	X			X	X
Mlama mweusi	*Combretum molle*	X	X	X	X		
Mfumbili	*Lonchocarpus capassa*	X	-				
Msisimizi	*Albizia harvey*	X	X				
Mgovu	*Pteleopsis myrtifolia*	-	-				
Mnyenye	*Xeroderris stuhrmanii*	-	-			-	X
Mtanga	*Terminanalia mollis*	X	X	X	X		
Kifunganyu mbu	*Acacia nilotica*	X	X				
Msolo	*Pseudolachnostylis maprouneifolia*	X	X			X	X
Mtogo	*Diplorhynchus condylocarpon*	X	X				
Mlama mwekundu	*Combretum zeyheri*	X	X				
Mguluka	*Boscia salicifolia*	-	-				
Kisasa	*Acacia goetzei subsp. Goetzei*	X	X				
Myombo	*Brachystegia boehmii*	X	X				
Mharaka	*Spirostachys africana*			-	-	-	-
Mlama mwekundu	*C. zeyheri*			X	X		
Mlama ng'ombe	*C. adonogonia*			X	X		
Mkongo	*Afzelia quanzensis*					-	-
Mninga	*Pterocarpus angolensis*					X	X
Mpingo	*Dalbergia melanoxylon*					X	X
Mninga maji	*Pterocarpus rotundifolius*					-	-

Mpilipili	*Sorindeia madagascariensis*			X	-
Mkurungo	*Brachystegia spp.*			-	-
	Brachylaena huillensis			-	-
	Isoberlinial spp.			-	-

5 Discussion

5.1 Carbon stock

The overall carbon stock in above- and below-ground biomass was found in the result to be lower in the protected forest than in the unprotected forest but the protected forest stored a larger amount of biomass in each tree and that can be explained to the fact that the trees were generally higher in the protected forest. This was not consistent with results from Zahabu (2008), which concluded that the protected forest had a higher carbon stock in above- and below-ground biomass than the unprotected forest. The respondents in the interviews, who suggested that the carbon stock was higher in the protected forest than in the unprotected forest and that the protected forest contained more trees, supported this.

Comparing results for carbon stock in above and below ground biomass from this study with results from Zahabu (2008) for the protected forest showed that the data was within the same magnitude, with 23,5 tC/ha and 21,1 tC/ha respectively (see Table 6 and Table 1). This gives an indication that the result for the protected forest is reliable. It can also be noticed an increase in carbon stock in AGB and BGB from 2005 years levels. That was the expected case in the protected forest since most resource extractions were prohibited, which allow the biomass to regenerate. The values in this report were probably slightly underestimated as carbon from deadwood, litter and trees with DBH below 10 cm were excluded in this study but included in the prior study.

When comparing data from this study with data from Zahabu (2008) for the unprotected forest, a significant difference is noticed. Carbon stock in above and below ground biomass for this study was 25,1 tC/ha, while the historical data was 3,5 tC/ha (see Table 6 and Table 1). A number of 3,5 tC/ha represent an extremely degraded forest area and are not even close to the average values of Miombo discussed in the theory chapter i.e. 23,1 tC/ha. It is doubtful if such low value can even be classified as a forest. Zahabu's study was chosen as a comparison as it is a relatively recent study preformed in 2008 and both this study and that study use biomass equations constructed by the same authors (chapter 2.2.1). Furthermore placement of the plots was in the same location in the protected forest and close to the plots for the unprotected forest investigated in this report. However the comparative study used allometric equation that did not include the tree height and the plots in the unprotected forest were located closer to the highway. The ideal case for comparison would be to use the exact same equation and locate the plots at exactly the same place as previous studies, but those areas could not be classified as a forest today. They had been subjected to land-use change and shifting cultivation already before 2008 (see 3.1). However, the plot locations in this thesis give an added value to the research field because it provides more detailed data for areas around Gwata and Mazizi. The sites have little or no prior mapping of carbon stock and system services. This study has focused on unprotected forest that has not been exposed to any other land uses than forestry, seen from the results prior studies has been done in shifting cultivations and agricultural lands. This results in data from the unprotected forest case, which is in a better condition than prior studies. Additionally no prior studies have been done with the approach of carbon stock and system services with focus on only Gwata and Mazizi, the prior studies have included the whole area of Kitulangalo.

Carbon content in soil was 1,9 % in the protected forest and 1,6 % in the unprotected forest and both values are within the range of historical data, suggesting they are reliable. The soil texture analysis showed that the soil condition in the two forest systems for clay and silt content were very similar which indicates that the difference in carbon soil content can not be attributed to the soil texture. However, the standard deviation for soil content in both protected and unprotected forest was high, 0,60 and 0,54 respectively, suggesting heterogeneous soil conditions in both forests.

When comparing the values of carbon stock calculated with the equation specially developed for Kitulangalo (equation 1) with the values from an equation developed for dry tropical forest (equation 2) it was found that the values where in roughly the same magnitude and that reinforces that the result is reliable (see Figure 7 and Figure 8). Equation 2 had a tendency to overestimate the carbon stock in above and below ground biomass when there was a high average DBH in the plot and a low average height. A source of error in that equation could be the lack of tree specific densities and it is believed that the originally used equation was the best alternative in this report because of that circumstance and also since it is specially developed for Kitulangalo. The values in carbon stock for above and below ground biomass varies widely among plots with a confidence interval of 23,5±5,02 and 25,1±5,03 for the protected and the unprotected forest respectively. That the result with 95 percent likelihood varies in a span of ±5,02 and ±5,03 indicates an uncertainty in the measurements. The great variation within these forest systems is believed to be connected to the plot's distance from the roadside, which could imply that the forest is stratified with different levels of degradation due to accessibility. This is not statistically stated in this thesis but highlighted both from interviewed scientists and observed from the performer of this thesis. An additional reason for variation in the unprotected forest could be that the plots were taken from both Gwata and Mazizi and those two locations may be in different degradation conditions. This difference in degradation conditions may be party because Gwata is located closer to the highway and partly because Gwata is exposed to more extensive degradation mechanisms such as higher population than Mazizi.

Possible sources of errors when the field measurements were performed could have been when estimating the height of the trees since that estimate was relatively approximate and this parameter influences the total carbon stock in above-ground biomass to a high extent. Another source of error was the fact that the plots where moved when their original GPS coordinates were found to be place in a water source. The plots were moved with the believe that it would undermine the statistical certainty of the study since there was only 30 plots from each forest case in this study and the forest in the water sources was by observation radically different from the other plots. If these plots were not moved the carbon stock in above and below-ground biomass would probably increased since the number of trees and the size of each tree where observed to be higher in those areas.

5.2 Biodiversity

The overall number of species was higher in the unprotected forest compared with the protected with 54 and 50 species respectively. This result indicates that the unprotected forest has a higher level of biodiversity in terms of number of species. However the results also shows that the protected forest was to a higher degree predominated of trees characteristic for Miombo woodland. One possible explanation is that *Julbernardia globiflora,* a common tree species in Miombo woodlands, is among the most preferable species for charcoal making and has therefore already been harvested to a high extent in the unprotected forest. This species is also useful for other system services such as for timber production and this makes *Julbernardia globiflora* attractive to harvest. *Combretum molle* was the most common species in both forest but represented to a higher frequency in the protected forest, which possibly can be explained by the fact that this species is suitable for building poles. Results from the interviews indicated that building poles and timber were two attractive system services for the local population and are system services they wish to extract to a higher degree.

Results are again compared with data from Zahabu (2008) and also with Malimbwi et al. (2001). A change in species composition can be noticed in both the protected and the unprotected forest when making this comparison (an overview is found in Table 8). In the following section a comparison of biodiversity in the protected forest is done between this study and Zahabu's research since both studies have identical plot locations.

Julbernardia globiflora, Brachystegia boehmii, Acacia nigrescens and *Sclerocarya birrea* were presented among the most common species in historical findings but to a higher percentage than today's result in the protected forest. This result suggests a loss in biodiversity since the most common species has decreased in dominance from 2008 and since the most dominated species today (*Combretum molle*) is not a species characteristic for Miombo. When making these conclusions it should be kept in mind that the frequency for the top ten most common species in this report was based on number of species while prior data was based on biomass content, which may provide a difference. Overall the total number of species has decreased from 56 to 50 in the protected forest from 2008 (see Table 8), which also indicates a loss in biodiversity. In the next section a comparison of biodiversity in the unprotected forest is done between this study and prior research from 2001 and 2008. In all studies the unprotected forest represent the same management system in areas located adjacent to each other. The data from 2001 and 2008 are located at the exact same site as mentioned in the theory chapter but the data from today is not.

The difference in number of tree species between the two studies is striking, with a total of 21 tree species in 2008 and 54 for this study for the unprotected forest (see Table 8). One explanation for this significant difference could be that the plots were not located at the exact same place and plots from historical data were placed closer to the highway. However data from 2001 stated a number of 44 observed species, thus historical data indicate that it has been a remarkably decrease in species between 2001 and 2008. The number of species is probably non-existing in that area today since it is observed to be agricultural land (discussed in previous chapter). This implies that the degradation mechanisms, once they have started, are extremely rapid in the unprotected forest. The number of species for this study in the unprotected forest was better that the one from 2001 and therefore considered to be in a rather good condition. The fact that some parts of the unprotected forest are maximally degraded and some parts are more or less intact, implies that degradation mechanisms does not occur evenly throughout the unprotected forest. *Xeroderris stuhlmannii* was the most dominant species for the unprotected forest in the prior study and not present among the most common trees in this study. An explanation could be, as mentioned in (see 3.2), that this is a species used for timber and that could have been left untouched intentionally in 2008 for later harvest. *Brachystegia boehmii* was present to a higher extent in 2008 compared with today in the unprotected forest, which indicates a decrease of this species.

5.3 Interviews

During the interview there were indications of discrepancies between the statements from researchers and those from local people. It seems like the view on most important system services and threats was rather similar within each group but less consistent between the two groups.

A very likely source of errors in the interviews is the fact that it was not a complete qualitative analysis, it was a simplification inspired by the case study methodology described in chapter 2.4. This incomplete approach was chosen simply because a full qualitative analysis would exceed the scope of this study and the simplified parts is further explained in the COREQ checklist presented in Appendix VIII and Appendix IX.

5.4 System services

The protected forest had a higher potential in providing charcoal and timber while the unprotected forest had a higher potential for building poles. The result where the unprotected forest was better at providing building poles was not expected since the protected forest was considered to have greater potential in providing system services as earlier mentioned. The following discussion addresses this phenomenon, compares the result with previous findings and discusses the validity of the result.

The result for system services revealed that the protected forest had a better potential in providing trees suitable for charcoal making compared to the unprotected forest (Figure 11 and Figure 12). This goes in line with results from Malimbwi et al. (2001), which states that the protected forest has a higher potential for charcoal. However, Malimbwi et al. (2001) found that the protected forest had more than twice as good potential as the unprotected forest in providing this system service while the difference was not that large in the findings of this thesis. The differences in result between the historical study and this study can be explained by the fact that the plots for the unprotected forest in this study was located at a different place than the plots in Malimbwi, Zahabu and Monela's study. The smaller difference in this study compared to historical values, could imply that some illegal harvesting occurs in the protected forest. This implication was supported by indications from the interviews that illegal harvesting in the protected forest occurred and furthermore this was a consequence of forest accessibility (which is further discussed in the next section).

There were no available data from previous studies on the potential of the two forest cases to provide trees suitable for building poles, making the result difficult to evaluate. The protected forest illustrates a notable higher potential for building poles than the unprotected. From the interviews it was indicated that building poles was one of the most important system services that the local people wished to extract to a higher extent than today. As stated in the result the only species that was listed among species suitable for building poles and not represented at all in any of the forest cases was *Spirostachys Africana.* This could probably be because this species was the most preferred species for building poles and probably consumed to a high rate.

None of the two forests seemed to have a high potential in providing trees for timber production since the biomass was low for those trees, even if the unprotected forest presented a higher potential. A low timber potential goes in line with findings from Malimbwi and Mugashi's study (2001). The explanation why *Afzelia quanzensis* and *Brachylaena huillensis* was not found in any of the forest, could be because they represent the category of the most preferred species for timber and therefore have already been harvested. However, this does not explain why there were no small trees of those species (too small for timber production) in the forests, but it could be connected to the lack of large trees that could spread seeds. *Pterocarpus angolensis* is also included in the category for most preferred species for timber but on the contrary to *Afzelia quanzensis* and *Brachylaena huillensis,* this species was represented at a higher rate in the unprotected forest, which confirms that this forest has higher potential of providing trees for timber production.

A source of error could be that the people around Mazizi preferred other species than the ones listed in this thesis since other species may be more easily accessed there. To get a more reliable result a survey study that asked all people around the village what tree species they use would have been a better alternative, but that would have been too time consuming for this study.

5.5 Drivers – Accessibility and population growth

The forest is exposed to many threats and factors, which determines the rate of forest degradation, some more difficult to control than others. From interviews two drivers were indicated as extra difficult to manage because they can be categorised as external drivers, meaning the local government and population have very little possibility to influence the development of these drivers. For that reason the following discussion will take focus on these two parameters because they are drivers local stakeholder will have to accommodate for, rather than manage.

The two forests investigated in this thesis was exposed to external pressure from two main drivers; accessibility and population growth according to indications from the interviews. Drivers, which increases the demand for resource extraction (see 3.3.1 and 3.3.3) from the forests and thus intensifies degradation mechanisms connected to extraction.

One of the main highways in Tanzania passes right by the two forests and this creates a second demand on the forests on top of the local demand. Historical data from unknown date concluded that the selling price for charcoal was about 40 % higher by the road side than by the kiln site and in 2005 the sell price was 133 % higher at the road side than at production site (see 3.3.1). The increased price gives incentives for increased resource extraction since 81 % of the people living in the close by villages make their living on agriculture and charcoal extraction. The highway also opens up the possibility for people from the region to travel to the two forests to extract resources. The highway acts as an access point to the forests and the human pressure is higher closer to the highway (see chapter 2.1). The interviews conducted indicated that respondents acknowledged accessibility as a driver for increased resource extraction. The researchers distinguished this driver as one of the main sources of human pressure of these specific forests and raised concern of how, or even if, a forest this close to a highway could be preserved. The local people recognised the driver by speaking of extracting for local need or extracting for selling and depicted the problems of the situation in similar ways as the anecdote 'tragedy of the commons'[11].

Increasing population in the area means more people sharing a finite amount of natural resources and this is valid for Gwata since the number of households in Gwata increased with around 80 % between 1995 and 2005 (see 3.1). From the interviews population growth was identified as one of the most important concerns for the future of the forests. Respondents identified this area as popular for urbanisation and people from all over Tanzania moved to the area because of the lucrative land use opportunities. This is backed up by historical research mentioned in theory (see chapter 3.1) that indicates that a majority of the people living in Gwata are from outside the area and in ten years they expected the population in the area to double compared to today. A population increase this high will have serious consequences for the future demand on the two forests.

[11] The tragedy of the commons is a case where depletion of shared resouces takes place and is caused by individuals, acting independently and rationally according to each one's self-interest. Regardless of their understanding that depleting the shared resource will damage the interest of the group in the future.

The two drivers are expected to increase extraction from both forest systems, by legal extraction in the unprotected forest and by illegal extraction in the protected forest, which has already been indicated as a problem from the interviews. From interviews it was indiated that both researchers and local people did not expect that neither the protected nor the unprotected forest would exist in ten years. It was said that it would not be economically feasible to guard the protected forest from illegal extraction to the required extent in the future and the unprotected forest was assumed to be completely deforested due to resource extraction in ten years time. This is very problematic since such a large proportion of the population living in the area is heavily dependent on forest resources to sustain their livelihood, 81 % are said to gain income from agriculture and charcoal extraction where both income sources are affected by negatively by deforestation.

5.6 Scientific value and further research

This report is done in an area where much research has been done previously since Kitulangalo forest reserve is managed by the Sokoine University of Agriculture with purpose to act as a research forest (mentioned chapter 1.2.3). This thesis adds to the scientific field for three reasons:

1. Data collection plots for the protected forest where party identical with previous plots in Kitulangalo forest reserve, which gives updated information about the forest condition and forest evaluation always requires updated data. This study gives an additional value in historical data series, which gives information about history and trajectory of forest development/degradation.
2. Data collection plots for the unprotected forest where placed on location where no prior data has been collected, thus adding to the overall carbon stock mapping of the area. For future assessment this could be an essential reference point. By placing the plots nearby Gwata and Mazizi this thesis has a more site-specific approach than historical data that includes a larges area with more villages. This allows for a more precise definition of local needs.
3. This thesis originate its focus from a local perspective and their needs of system services to a higher extent than previous studies e.g. by including several system services that has been deemed vital for the people in Gwata.

Further research could be to include and quantify more system services not only connected to specific trees but also to an ecosystem level such as species symbioses and their correlation. Quantification both in terms of what the forest can provide and also what amount the local people need. More threats could be evaluated in similar ways as system services and future possible scenarios could be developed. The biological diversity could be evaluated more extensively by adding parameters such as animals and other living organisms, but also identify invasive species and develop biodiversity indicators.

6 Conclusions

Research question 1: How large is the carbon stock in above-ground and below-ground biomass and what is the soil carbon content, in two forest systems?

- The carbon stock in above-ground and below-ground biomass was 23,5 tC/ha and 25,1 tC/ha for the protected forest and the unprotected forest respectively.

The protected forest had a smaller carbon stock in above- and below-ground biomass than the unprotected forest, which was surprising since the historical data had indicated the opposite. The findings showed that the two forest systems were in similar conditions with respect to carbon stock. If these values are compared to the value of carbon stock for Miombo woodlands in general i.e. 28 tC/ha for AGB and BGB, it is possible to conclude that both forests are rather close to the values for Miombo in general. Calculated biomass values were in line with calculated values when using another biomass equation, which indicates that the results are reliable.

- The soil carbon content was 1,86 $\%_{mass}$ and 1,61 $\%_{mass}$ for the protected forest and the unprotected forest respectively.

The carbon content in soil was higher in the protected forest than in the unprotected forest, which is consistent with historical data. The results indicate that the protected forest was in a better condition than the unprotected forest with respect to soil carbon. Both values were in the same magnitude as prior studies, which suggest that the results are reliable.

Research question 2: Does the biodiversity of trees differ between the two forests?

The over-all number of tree species in the protected forest was smaller than in the unprotected forest with 50 and 54 species respectively. However, the protected forest was to a higher degree predominant of trees characteristic for Miombo woodlands. The top ten most common tree species represented a higher percentage of the total number of trees in the protected forest than in the unprotected forest. When comparing with historical data, the protected forest has decreased in species richness with only a few species since 2008 and unprotected forest has increased significantly, more than doubled, in species richness since 2008. This could question the reliability of the results and it is most likely connected to differences in plot location between historical and present study.

Research question 3: Which system services are most important for the local people in order to contribute to their livelihood and what are the possibilities for the two forests to provide these services?

Most important local system services that could be connected to tree species and DBH classes were; charcoal, building poles and timber. The protected forest had a lower potential of providing trees suitable for timber production than the unprotected forest but a higher potential in providing trees for charcoal making and building poles. When comparing with historical data the findings for charcoal was in line with prior finding but the difference between the forests is smaller today than it was historically. The potential for timber production was low in both forests, which is consistent with historical data. There were no historical data for building poles.

Research question 4: What are the major pressures for the specific forest systems and what are the possible future potentials in terms of carbon stock and system services?

The major pressures identified in this thesis were accessibility to the forest from the Dar es Salaam highway and population growth in the area surrounding the two forest systems. The future potential of the forest systems was not analysed in detail but some common reasoning identified during the research of this thesis will be further explored later in this section.

Findings from the research questions depict two forests in relatively similar ecosystem conditions with respect to the investigated parameters with an indication that the unprotected forest is in a slightly better condition in terms of above- and below-ground carbon stock and timber while the protected were better in terms of building poles and charcoal. Nevertheless, the opposite was belied by a majority of the interviewees who believed that the protected forest was in a better condition than the unprotected forest. The differences between the forests was said to be obvious just by looking at the forests, because they do not even look the same. The unprotected forest was said to contain fewer trees than the protected forest; that some tree species are no longer found in the unprotected forest and it was stated that it is getting harder for the local people to extract the system services they want from the unprotected forest because it is highly degraded. Some of these statements are also supported in historical data. Even if the believed condition from historical data and interviewees do not go in line with the findings from the research question, there are other parameters that reinforce this image. These parameters are mentioned below:

- The number of trees counted in each forest system was 574 and 685 for the protected forest and the unprotected forest respectively.
- The number of stumps found in each forest system was 3 and 111 for the protected forest and the unprotected forest respectively.
- Trees in protected forest were taller and contained more biomass per tree for all DBH classes than trees in the unprotected forest.
- Charcoal making pits and clear cutting were observed in the unprotected forest.
- Lower amount of deadwood was observed in the unprotected forest.

Interpretation of these significant differences could be that the unprotected forest is exposed to higher pressure, more trees seem to be felled for system services extraction. This suggests that the biomass stock is decreasing in the unprotected forest but that it originally was higher than in the protected forest.

Deforestation is a known problem in Tanzania and especially in the forest case studied in this thesis considering the drivers involved. The forests around Gwata and Mazizi are likely to be cleared and the area will be exposed to land use change in the future even though it is in a relatively good condition today. The researchers interviewed in this study indicated that they wanted to preserve the forest for global services by protecting the forest from the local people; they do not talk about the local peoples needs to extract resources from the forest for their livelihood. A sustainable solution could be to have a forest with SFM where it would be possible to extract resources to contribute to the local peoples livelihood and at the same time maintain the forest condition, meaning the extraction rate does not exceed the regrowth rate of the forest. Though the findings of this thesis suggests that such a scenario would be difficult in this specific case since the forest is simply to small to provide resources in the required extent. However, the study concludes that the current forest utilisation is far from perfect and there are many factors that can be improved to increase the forest usage efficiency. Many of the improvements could possibly be done by different management schemes. It is also important to stop systematically clear cutting good forest for agricultural expansion to promote sustainable development.

7 References

Baxter, P., Jack, S., 2008. Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. The Qualitative Report Volume 13, 544–559.

Bigham, G., 2010. The science of soil textures. Science Scope 34, 63–68.

Bisutti, I., Hilke, I., Raessler, M., 2004. Determination of total organic carbon – an overview of current methods. TrAC Trends in Analytical Chemistry 23, 716–726.

Campbell, B., 1996. , in: The Miombo in Transition: Woodlands and Welfare in Africa. CIFOR.

Campbell, B., Byron, N., n.d. Miombo woodlands and rural livelihoods: Options and opportunities.

Campbell, B., Frost, P., Byron, N., 1996. Miombo Woodlands and their use: Overview and key issues. CIFOR, Indonesia.

Chamshama, S.A.., Mugasha, A.., Zahabu, E., 2004. Stand Biomass and Volume Estimation for Miombo Woodlands at Kitulangalo, Morogoro, Tanzania. Southern African Forestry Journal 200, 59–69.

Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.-P., Nelson, B.W., Ogawa, H., Puig, H., Riéra, B., Yamakura, T., 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145, 87–99.

FAO, 2010. Global Forest Resources Assessment 2010 (Main Report). Rome: Author.

FAO, 2011. State of the World's Forests.

Frost, P., n.d. The Ecology of Miombo Woodlands.

Hancock, B., 1998. Trent Focus for Research and Development in Primary Health Care - An Introduction to Qualitative Research.

Holmes, J., 1995. Natural Forest Handbook for Tanzania. Forest ecology and management. Sokoine University of Agriculture, Faculty of Forestry, Morogoro, Tanzania.

IPCC, 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Institut for Global Environmental Strategies, Hayama, Japan.

Isango, J.A., n.d. Stand Structure and Tree Species Composition of Tanzania Miombo Woodlands: A Case Study from Miombo Woodlands of Community Based Forest Management in Iringa District.

Jain, T.B., Graham, R.T., Adams, D., 2010. Carbon Concentrations and Carbon Pool Distributions in Dry, Moist, and Cold Mid-Aged Forests of the Rocky Mountains (USDA Forest Service Proceedings RMRS-P-61). USA.

Ketterings, Q.., Coe, R., Van Noordwijk, M., Ambagau, Y., Palm, C.., 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. Forest Ecology and Management 146, 199–209.

Lamlom, S.H., Savidge, R.A., 2003. A reassessment of carbon content in wood: variation within and between 41 North American species. Biomass & Bioenergy - BIOMASS BIOENERG vol. 25, no. 4, 381–388.

Lulandala, L., n.d. Use of the Kitulangalo plots and study results in education at Sokoine University of Agriculture and beyond: current and future considerations.

Luoga, E.J., Witkowski, E.T.F., Balkwill, K., 2000. Differential utilization and ethnobotant of trees in Kitulanghalo forest reserve and sorrounding communal lands, Eastern Tanzania. Economic Botany 45, 328–343.

Makonda, F., 2012. Discussion about tree species and system services.

Malimbwi, R.E., Misana, S., Monela, G.C., Jambiya, G., Zahabu, E., n.d. Impact of charcoal extraction to the forest resources of Tanzania: The case of Kitulagalo area, Tanzania (CHAPOSA (Impact of Charcoal Extraction to the Forest Resources of Tanzania)). Tanzania.

Malimbwi, R.E., Mugasha, A.., 2001. Inventory report of Kitulangalo forest reserve in Morogoro, Tanzania. Faculty of Forestry and Nature Conservation, Sokoine University of Agriculture, Morogoro, Tanzania.

Malimbwi, R.E., Mugasha, A.G., 2000. Forest Inventory Report for the Rufiji Forests. (Consultant report, FORCONSULT). Faculty of Forestry & Nature Conservation, SUA, Morogoro, Tanzania.
Malimbwi, R.E., Solberg, B., Luoga, E., 1994. Estimation of biomass and volume in Miombo Woodland at Kitulangalo forest reserve, Tanzania. Journal of Tropical Forest Science 7, 230–242.
Malimbwi, R.E., Zahabu, E., Monela, G.C., 2001. Charcoal potential of Miombo woodlands at Kitulangalo, Tanzania. Journal of Tropical Forest Science 17, 192–210.
Maliondo, S.M.S., Abeli, W.S., Meiludie, R.E.L., Migunga, G.A., Kimaro, A.A., 2005. Tree species composition and potential timber production of a communal Miombo woodland in Handeni destrict, Tanzania. Journal of Tropical Forest Science 17, 104–120.
Mbwambo, L., 2012. Meeting at Tafori.
Msanya, B.M., Kimaro, D.N., Shayo-Ngowi, A.J., 1995. Soils of Kitulangalo Forest Reserve area, Morogoro district, Tanzania. Department of Soil Science, SUA, Morogoro, Tanzania.
Nduwamungu, J., Munishi, P., Bloesch, U., Hagedom, F., Lulu, K., 2009. Recent land cover and use changes in miombo woodlands of eastern Tanzania. Tanzania Journal of Forestry and Nature Conservation 2009, 50–59.
Nord, H., 2008. Water infiltration under different land use in miombo woodlands outside Morogoro, Tanzania (Examensarbete). Institutionen för skogens ekologi och skötsel, SLU.
Nyberg, G., 2012. Conferance in Uppsala.
Obiri, J.A.F., Hall, J.B., Healey, J.R., 2010. Composition, Structure and Regeneration of Miombo Forest at Kitulangalo, Tanzania. Earthscan, UK.
Pamela Baxter, Susan Jack, 2008. Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. The Qualitative Report Volume 13, 544–559.
Particle Size Analysis, 2006. , in: Handbook of Soil Analysis. Springer Berlin Heidelberg, pp. 15–63.
Pearson, T., Walker, S., Brown, S., 2005. Sourcebook for Land use, Land-use change and forestry Projects.
Ravindranath, N.., Ostwald, M., 2008. Carbon Inventory Methods: Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Roundwood Production Projects. Springer Science + Business Media B.V.
Reyes, G., Brown, S., Chapman, J., Lugo, A.E., 1992. Wood densities of Tropical Tree Species (General Technical Report S0-88). United States department of Agriculture, New Orleans, Lousiana.
Shirima, D., Munishi, P., Lewis, S., Burgess, N., Marshall, A.R., Balmford, A., Swetnam, R.D., Zahabu, E.M., 2011. Carbon storage, structure and composition of miombo woodlands in Tanzania's Eastern Arc Mountains. African Journal of Ecology 49, 332–342.
The Montréal Process, 2012. Joint statement of The Montréal Process, International Tropical Timber Organization, FOREST EUROPE, and the Food and Agriculture Organization of the United Nations' Global Forest Resources Assessment on sustainable forest management.
The united republic of Tanzania, 2001. National and biodiversity action plan.
The United Republic of Tanzania - Ministry of Natural Resources & Tourism, 2010. Species list - sorted by vernacular names (common names) (NAFORMA DOCUMENT No. M06b-2010). National Forestry Resources Monitoring and Assessment of Tanzania (NAFORMA), Dar es Salaam, Tanzania.
Tong, A., Sainsbury, P., Craig, J., 2007. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. Int J Qual Health Care 19, 349–357.
Vännman, K., 2002. Matematisk statestik, 2:7 ed. Studentlitteratur.
Walker, S.M., Desanker, P.V., 2004. The impact of land use on soil carbon in Miombo Woodlands of Malawi. Forest Ecology and Management 203, 345–360.

Zahabu, E., 2008. Sinks and Sources - A strategy to involve forest communities in Tanzania in global climate policy.

Appendix I. Laboratory instructions for organic carbon by wet oxidation

Reagents

Potassium dichromate solution 0.1667M $K_2Cr_2O_7$

Dry 50-52g of $K_2Cr_2O_7$ at 105-110°C for at least 2 hours, cool to ambient temperature in a desiccator. Weigh 49.04g of $K_2Cr_2O_7$ to a 1 litre beaker, dissolve it in approximately 800ml H_2O. Transfer the content to a 1000ml volumetric flask. Add H_2O to mark, mix and store the solution in a brown bottle.

Ammonium ferrous sulfate solution 0.5M $(NH_4)_2Fe(SO_4)_2 \cdot 6H_2O$

Weigh 196g ammonium ferrous sulfate into a 500ml beaker, dissolve and transfer the content to a 1000ml volumetric flask and dilute to approximately 700ml. Add slowly under swirling 20ml of 96-98% H_2SO_4. Cool to ambient temperature and fill to mark with water. Mix and transfer the solution to a brown bottle.

Phosphoric acid 85% H_3PO_4

Indicator solution 0.16% Diphenylamide-4-sulfonic acid barium salt

Dissolve 0.4g diphenylamide-4-sulfonic acid barium salt in 250ml H_2O. Start dissolving it a day before sue, as it is difficult to bring into solution.

Determination of the normality (equivalent rate) of the $FeSO_4$ solution

Transfer 10ml of the 0.1667M $K_2Cr_2O_7$ solution by means of a pipette to a conical flask. Add 2ml of the indicator solution, and titrate with the approximately 0.5M $FeSO_4$ solution to colour change to green.

Analytical procedure:

Weigh 1g (with an accuracy of 1mg on an analytical balance) of finely grained soil into a 500ml wide-mouth conical flask. If the soil is expected to contain more than about 2.5% organic C use only 0.4-0.8g of soil – depending on the expected organic carbon content.
If the content of organic carbon is very high e.g. in soil with a histic horizon, use twice the amount of reagent, except for the blanks.
Pipette 10ml of the potassium dichromate solution to the soil. Add 20ml of 96-98% H_2SO_4, using a dispenser. Swirl the flask carefully and allow standing for 30 minutes. Add 200ml of H_2O and allow cooling. Then add 10ml of 85% H_3PO_4, using a dispenser.
Add 2ml of the indicator solution and titrate with ferrous sulfate while stirring. The colour changes from brown to purple to blue and finally to green. The last change of colour is very abrupt. More than 6ml of ferrous sulfate should be used for the titration, if the amount used, is lower, the analysis is repeated using less soil. Beside titration the soil sample titrate also two blanks.

Organic carbon (%) = (meq $K_2Cr_2O_7$ –meq $FeSO_4$) · 0.3 · f · MCF · 1/m

MCF = moisture correction factor (assumed 1 for dry soils)
f = correction factor of the organic not oxidized by the treatment (normally approximately 1.3)
m = g of soil

Reference:

Walkley, A and Black, I.A. 1934. An examination of the Degtjareff method for determining soils organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 63:251-263.

Black, C.A., Evans, D.D, White, J.L., Ensminger, L.E., and clark, F.E. 1965. Methods of Soil Analysis. Part 2, Agron. Monogr. 9. ASA and SSSA, Madison, Wisconsin, USA.

Appendix II. Laboratory instructions for Particle size analysis

Reagents
Amyl alcohol

Dispersal solution 5 % calgon in H_2O
Dissolve 20g sodium hexametaphosphate (calgon) and 8g sodium hydroxide in warm H_2O, cool and dilute to 1litre.

Apparatus/Equipment
Bouyocous hydrometer
Graduated cylinder (1litre)
Brass plunger
Thermometer
Balance
Stop watch
Sieve (0.2mm opening)
Tall beakers

Procedure:
1. Weigh 50g air-dry soil (<2mm)
2. Add accurately 150ml of the dispersal solution and about 150ml of H_2O
3. Disperse the soil for 5 minutes while stirring
4. Transfer the dispersed suspension to the sedimentation graduated cylinder and then add H_2O to make the volume 900 ml
5. Allow the suspension to cool (preferably overnight) and add more water to make the volume to 1 litre
6. If there is frothing, quell it with one or two drops of amyl alcohol
7. Homogenize the solution
8. After mixing, record the time immediately
9. After 4 minutes, lower a hydrometer carefully into the suspension and take the reading (R1) exactly 5 minutes after mixing
10. Remove hydrometer carefully and record temperature (T1)
11. Repeat the hydrometer and temperature readings; R2 and T2, exactly 5 hours after recording T1
12. Calibrate hydrometer in blank sample
13. Homogenize and take readings 5 minutes after mixing (Rbi) and 5 hours (Rbii)
14. Correct the hydrometer readings based on a temperature of 20°C. For every degree over 20°C add 0.36 units to the hydrometer reading and for every degree below 20°C subtract 0.36 units. Avoid extreme temperatures such as 10°C and 38°C

Calculations:
For each reading, calculate the concentration of the suspension (g/l) as follows:
$Ci=[R1-Rbi + 0.36(T1-20)]$ [g/l]
$Cii= \{R2-Rbii + 0.36[0.5(T1+T2)-20]\}$ [g/l]

Ci= concentration of silt + clay [g/l]
Cii= concentration of clay [g/]
Ci-Cii= concentration of sol [g/l]

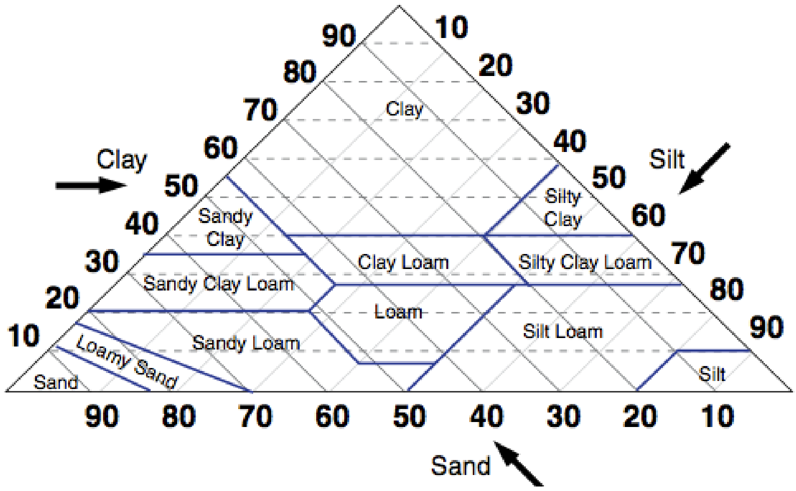
The percentage of suspended material (sand + silt + clay) is calculated as:

% suspended material = hydrometer reading / air-dry weight of soil · 100%

% silt = concentration of silt / 50g · 100% = [(Ci-Cii) / 50] · 100% = 2(Ci-Cii)%

% clay = concentration of clay / 50g · 100% = [(Cii) / 50] · 100% = 2Cii %

% sand = 100% - % silt - % clay



Figur 1 Soil texture triangle. Source: (Bigham, 2010)

Appendix III. Carbon stock for each plot with two different equations

Plot nr	Location	Mean dbh	Mean hight	Carbon/plot (t/ha) Equation 1	Carbon/plot (t/ha) Equation 2
1	Protected forest	19	7.6	23	23
2	Protected forest	18	6.7	8.7	10
3	Protected forest	19	7.6	9.2	9.4
4	Protected forest	18	6.2	8.6	10
5	Protected forest	22	6.1	12	15
6	Protected forest	27	7.5	28	31
7	Protected forest	22	10	15	11
8	Protected forest	19	5.7	8.5	12
9	Protected forest	17	6.6	6.3	6.9
10	Protected forest	20	7.4	27	25
11	Protected forest	17	9.3	24	19
12	Protected forest	19	9.4	35	33
13	Protected forest	19	8.3	21	18
14	Protected forest	22	8.5	23	23
15	Protected forest	18	7.4	20	19
16	Protected forest	23	8.0	22	20
17	Protected forest	17	6.7	13	14
18	Protected forest	21	10	29	21
19	Protected forest	23	7.0	23	24
20	Protected forest	24	11	53	44
21	Protected forest	24	10	29	21
22	Protected forest	23	7.5	24	21
23	Protected forest	22	8.1	30	24
24	Protected forest	22	7.9	17	15
25	Protected forest	19	7.1	13	12
26	Protected forest	19	7.3	28	26
27	Protected forest	17	6.3	5.8	6.5
28	Protected forest	16	5.4	3.2	4.0
29	Protected forest	16	4.7	8.1	10
30	Protected forest	19	7.5	11	12
31	Unprotected forest	22	9.3	29	24
32	Unprotected forest	20	6.3	15	17
33	Unprotected forest	19	6.3	19	18
34	Unprotected forest	19	4.6	8.7	14
35	Unprotected forest	22	7.4	19	19
36	Unprotected forest	22	6.5	20	22
37	Unprotected forest	17	4.8	7.4	10
38	Unprotected forest	18	7.3	20	20
39	Unprotected forest	27	8.2	20	21
40	Unprotected forest	9.1	2.4	5.1	7.2
41	Unprotected forest	16	5.5	11	13
42	Unprotected forest	20	7.4	15	15
43	Unprotected forest	17	3.8	1.9	3.5
44	Unprotected forest	20	8.4	19	22
45	Unprotected forest	21	8.4	28	24
46	Unprotected forest	19	7.1	9.4	10

47	Unprotected forest	17	6.0	10	12
48	Unprotected forest	19	7.6	28	24
49	Unprotected forest	22	9.4	37	30
50	Unprotected forest	30	7.5	41	44
51	Unprotected forest	20	6.5	16	16
52	Unprotected forest	35	7.6	31	33
53	Unprotected forest	20	7.8	10	9.2
54	Unprotected forest	23	7.8	42	40
55	Unprotected forest	21	7.1	19	20
56	Unprotected forest	26	7.8	28	30
57	Unprotected forest	29	8.6	43	38
58	Unprotected forest	28	6.5	35	44
59	Unprotected forest	25	6.3	23	29
60	Unprotected forest	19	6.5	18	18

Appendix IV. Most common tree species

Table 1; Most common tree species in protected forest

Local name	Latin name	Frequency (Nr)	Frequency (%)
Mlama mweusi	*Combretum molle*	89	16
Mnhondolo	*Julbernardia globiflora*	81	14
Mlama mweupe	*Combretum zeyheri*	33	5.8
Mtogo	*Diplorhynchus condylocarpon*	31	5.4
Msoto	*Dombeya rotundifolia*	30	5.3
Mkambala	*Acacia nigrescens*	28	4.9
Myombo	*Brachystegia boehmii*	27	4.7
Kisasa	*Acacia goetzei subsp. Goetzei*	25	4.4
Mcharaka	*Spirostachys africana*	24	4.2
Mkongowe	*Acacia robusta*	19	3.3
Mpingo	*Dalbergia melanoxylon*	19	3.3
Kifunganyumbu	*Acacia nilotica*	15	2.6
Mjengaua	*Ekebergia capensis*	12	2.1
Msisimizi	*Albizia harveyi*	11	1.9
Mzezegele	*Dalbergia nitidula*	11	1.9
Mtwintwi	*Commiphora pilosa*	10	1.8
Msinzira	*Bridelia cathartica*	9	1.6
Kikulagembe	*Dichrostachys cinerea*	8	1.4
Mng'ongo	*Sclerocarya birrea*	8	1.4
Msolo	*Pseudolachnostylis glauca*	8	1.4
Mfumbili	*Lonchocarpus Sp.*	6	1.1
Kisakulanhwale	*Margaritaria discoidea*	5	0.88
Mtanga	*Albizia versicolor*	5	0.88
Mzeza	*Dalbergia boehmii*	5	0.88
Mlama mwekundu	*Combretum collinum*	5	0.88
Mkulwi	*Diospyros loureiriana*	4	0.70
Mngoji	*Pteleopsis myrtifolia*	4	0.70
Msempele	*Rhus natalensis*	4	0.70
Mzinda nguuwe	*Blighia unijugata*	4	0.70
Mkole	*Grewia similis*	3	0.53
Mkwaju	*Tamarindus indica*	3	0.53
Mtutuma	*Catunaregam spinosa*	3	0.53
Mkunungu	*Zanthoxylum chalybeum*	2	0.35
Mlama ng'ombe	*Combretum adonogonium*	2	0.35
Moza	*Sterculia africana*	2	0.35
Manga	*Hagenia abyssinica*	1	0.18
Mbona	*Croton macrostachys*	1	0.18
Mdudu	*Ritchea albersii*	1	0.18
Mguruka	*Boscia salicifolia*	1	0.18
Mhembeti	*Sterculia quinqueloba*	1	0.18
Mnenekenda	*Elaedendron schlechterianum*	1	0.18
Mnhindipori	*Lannea schimperi*	1	0.18
Mninga	*Pterocarpus angolensis*	1	0.18
Mnumbu	*Lannea stuhlmannii*	1	0.18
Mpilipili	*Albizia antunesiana*	1	0.18
Mtindi	*Cussonia arborea*	1	0.18

Mtomoko	*Annona senegalensis*	1	0.18
Muhembe	*Pluchea ovalia*	1	0.18
Mkunde	*Cassia sp.*	1	0.18
Mnyenye	*Xeroderris stuhlmannii*	1	0.18
	Total nr of trees:	570	Other
	Nr of species:	50	31.9

Table 2; Most common tree species in unprotected forest

Local name	Latin name	Frequency(Nr)	Frequency (%)
Mlama mweusi	*Combretum molle*	78	12
Msoto	*Dombeya rotundifolia*	59	8.8
Mkongowe	*Acacia robusta*	39	5.8
Msinzira	*Bridelia cathartica*	37	5.5
Myombo	*Brachystegia boehmii*	30	4.5
Mngoji	*Pteleopsis myrtifolia*	27	4.0
Mkambala	*Acacia nigrescens*	24	3.6
Msempele	*Rhus natalensis*	23	3.4
Kikulagembe	*Dichrostachys cinerea*	22	3.3
Kifunganyumbu	*Acacia nilotica*	21	3.1
Kisasa	*Acacia goetzei subsp. Goetzei*	21	3.1
Mtogo	*Diplorhynchus condylocarpon*	19	2.8
Mjengaua	*Ekebergia capensis*	18	2.7
Mkole	*Grewia similis*	18	2.7
Mlama mweupe	*Combretum zeyheri*	14	2.1
Mpingo	*Dalbergia melanoxylon*	14	2.1
Mcharaka	*Spirostachys africana*	13	1.9
Mtanga	*Albizia versicolor*	13	1.9
Msolo	*Pseudolachnostylis glauca*	12	1.8
Mzezegele	*Dalbergia nitidula*	12	1.8
Kisakulanhwale	*Margaritaria discoidea*	11	1.6
Mkusu	*Uapaca kirkiana*	11	1.6
Mng'ongo	*Sclerocarya birrea*	11	1.6
Mnhondolo	*Julbernardia globiflora*	11	1.6
Msisimizi	*Albizia harveyi*	11	1.6
Mkilika	*Ehretia amoena*	10	1.5
Mzeza	*Dalbergia boehmii*	8	1.2
Mguruka	*Boscia salicifolia*	7	1.0
Mdaha	*Diospyros fischeri*	5	0.75
Mkwaju	*Tamarindus indica*	5	0.75
Mnumbu	*Lannea stuhlmannii*	5	0.75
Mzinda nguuwe	*Blighia unijugata*	5	0.75
Mdudu	*Ritchea albersii*	4	0.60
Mfuleta	*Albizia anthelmintica*	4	0.60
Mhamvi	*Millettia usaramensis*	4	0.60
Mlama mwekundu	*Combretum collinum*	4	0.60
Msungura	*Tarenna graveolens*	4	0.60
Mtwintwi	*Commiphora pilosa*	4	0.60
Bamba	*Euphorbia nyikae*	3	0.45
Mbwewe	*Canthium crassum*	3	0.45
Mlama ng'ombe	*Combretum adonogonium*	3	0.45
Mninga	*Pterocarpus angolensis*	3	0.45
Mfumbili	*Lonchocarpus Sp.*	2	0.30

Mkarati	*Medicinal, poles, fuel wood*	2		0.30
Mkenge	*Albizia petersiana*	2		0.30
Mkundekunde	*Cassia abbreviata*	2		0.30
Mtutuma	*Catunaregam spinosa*	2		0.30
Kilumbulumbu	*Ormocarpum kirkii*	1		0.15
Mkunungu	*Zanthoxylum chalybeum*	1		0.15
Mnyenye	*Xeroderris stuhlmannii*	1		0.15
Mlenda	*Cordyla africana*	1		0.15
Mnangu	*Byrsocarpus boivinianus*	1		0.15
Moza	*Sterculia africana*	1		0.15
Mtindi	*Cussonia arborea*	1		0.15
	Total nr of trees:	667	Other	
	Nr of species:	54		46.0

Appendix V. Biomass of trees that fulfilled criteria for charcoal

Table 3; Species prefered for charcoal

Species prefered for charcoal		Dbh classes	Biomass Protected	Biomass unprotected
Mnhindipori	*Lannea schimperi*			
		10-19	26.0	0
		20-29	0	0
		>=30	0	0
Mkambala	*Acacia nigrescens*			
		10-19	3478	845
		20-29	362	286
		>=30	470	2016
Mkongowe	*Acacia gerrardii*			
		10-19	629	2207
		20-29	789	4075
		>=30	433	1450
	Jurbernadia globiflora			
Mnhondolo		10-19	5621	536
		20-29	5830	442
		>=30	3359	240
Mlama mweusi	*Combretum molle*			
		10-19	8105	5196
		20-29	2177	1436
		>=30	1051	491
Mfumbili	*Lonchocarpus capassa*			
		10-19	648	39
		20-29	33	0
		>=30	0	0
Msisimizi	*Albizia harvey*			
		10-19	474	1230
		20-29	998	287
		>=30	518	511
Mngoji	*Pteleopsis myrtifolia*			
		10-19	187	1322
		20-29	0	1391
		>=30	0	1040
Mtanga	*Terminanalia mollis*			
		10-19	169	447
		20-29	282	100
		>=30	0	41
Kifunganyumbu	*Acacia nilotica*			
		10-19	4591	2869
		20-29	374	443
		>=30	0	0

Msolo	*Pseudolachnostylis maprouneifolia*			
		10-19	800	143
		20-29	732	60
		>=30	0	559
Mtogo	*Diplorhynchus condylocarpon*			
		10-19	872	1383
		20-29	773	572
		>=30	1472	609
Mlama mwekundu	*Combretum zeyheri*			
		10-19	10	652
		20-29	596	29
		>=30	0	0
Kisasa	*Acacia goetzei subsp. Goetzei*	10-19	2122	1681
		20-29	850	569
		>=30	399	271
Myombo	*Brachystegia boehmii*			
		10-19	1331	2236
		20-29	93	1293
		>=30	76	252

Appendix VI. Biomass of trees that fulfilled criteria for building poles

Table 4 Preferable species for building poles

Local name	Latine name	Dbh classes	Protected forest	Unprotected forest
			Biomass	
Mharaka	*Spirostachys africana*	10-19	0	0
		20-29	0	0
		>=30	0	0
Mlama mweusi	*Combretum molle*	10-19	8105	5196
		20-29	2177	1436
		>=30	1051	491
Mlama mwekundu	*C. zeyheri*	10-19	10	652
		20-29	596	29.1
		>=30	0.0	0.0
Mlama ng'ombe	*C. adonogonia*	10-19	0.0	249
		20-29	366	0.0
		>=30	0.0	0.0
Mtanga	*Terminalia mollis*	10-19	169	447
		20-29	282	99.7
		>=30	0	40.7

Appendix VII. Biomass of trees that fulfilled criteria for timber

Table 5; Species prefered for timber, DBH >= 30 cm

	DBH >=30	Protected forest	Unprotected forest
Mkongo	*Afzelia quanzensis*	0.0	0.0
Mninga	*Pterocarpus angolensis*	71.5	1248
Mpingo	*Dalbergia melanoxylon*	33	77.1
Mninga maji	*Pterocarpus rotundifolius*	0	0
Mnyenye	*Xeroderris stuhlmannii*	0	11.2
Mpilipili	*Sorindeia madagascariensis*	19	0.0
Mharaka	*Spirostachys africana*	0	0
Msolo	*Pseudolachnostylis maprouneifolia*	0	2853
Mkurungo	*Brachystegia spp.*	0	0
Mnhondolo	*Jurbernadia globiflora*	3359	240

Appendix VIII. COREQ list for interviews with researchers

Domain 1: Research team and reflexivity

Personal Characteristics
1. Interviewer/facilitator -*Which author/s conducted the interview or focus group?*
Andreas Särnberger, Lina Hammarstrand,

2. Credentials -*What were the researcher's credentials? E.g. PhD, MD*
M.Sc. students at Chalmers Technical University

3. Occupation -*What was their occupation at the time of the study?*
Students

4. Gender -*Was the researcher male or female?*
Andreas Särnberger – male
Lina Hammarstrand – female

5. Experience and training -*What experience or training did the researcher have?*
In qulitative analysis, no prior experience.

Relationship with participants
6. Relationship established -Was a relationship established prior to study commencement?
Yes, through meetings about forest research and we also got help with new ideas and input for our study.

7. *Participant knowledge of the interviewer -What did the participants know about the researcher? e.g. personal goals, reasons for doing the research*
Mixed, some of the researchers were involed in the project prior to interviews and had contributed with knowledge and data though no one was well informed of our study. Some of the interviewees had very little prior knowledge.

8. *Interviewer characteristics -What characteristics were reported about the interviewer/facilitator? e.g. Bias, assumptions, reasons and interests in the research topic*
None apparent characteristics were reported.

Domain 2: study design
Theoretical framework
9. *Methodological orientation and Theory -What methodological orientation was stated to underpin the study? e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis*
This study was not a full-blown quliative analysis thus no methodology was fully used. Though a case study approach was chosen, in some ways similar to phenomoenology though with more of a contextual focus. Parameters such as accessability to the highway and that the two forests investigated were very close to each other but under different management schemes.

Theory Participant selection
10. Sampling -*How were participants selected? e.g. purposive, convenience, consecutive, snowball*
Purposive – Researchers because of their field of expertice in the issue and of the prior knowledge and their own reserach in the area.

villagers because they had lived in the village for a long time and/or who had central village roles concerning the project issue.

11. Method of approach -*How were participants approached? e.g. face-to-face, telephone, mail, email*
Face-to-face

12. Sample size -*How many participants were in the study?*

Three researchers, all professors at Sokoine University of Agriculture with a focus on forest issues.

13. Non-participation -*How many people refused to participate or dropped out? Reasons?*
No one refused or dropped out.

Setting
14. Setting of data collection -*Where was the data collected? e.g. home, clinic, workplace*
The researchers were inverviewed at their offices.

15. Presence of non-participants -Was anyone else present besides the participants and researchers?
Only the two authors of this study was present at the interviews.

For villagers were translators present.

16. Description of sample -What are the important characteristics of the sample? e.g. demographic data, date
The three professors were chosen because they the subject was within their subject of expertise and because their expertise differed slightly so we could get a broader picture of the problem.

Data collection
17. Interview guide -Were questions, prompts, guides provided by the authors? Was it pilot tested?
It was a semi-structured interview, an over-all goal of the interview was given and open ended questions were used as a basis for the interview (both presented in the method chapter of the study)

18. Repeat interviews -Were repeat interviews carried out? If yes, how many?
No

19. Audio/visual recording -*Did the research use audio or visual recording to collect the data?*
Yes, audio for profesors.

20. Field notes -*Were field notes made during and/or after the interview or focus group?*
Yes

21. Duration -*What was the duration of the interviews or focus group?*
Around 30 to 45 minutes

22. Data saturation -*Was data saturation discussed?*
Interviewees were asked if they had anything to add. Some interviewees also noted that some questions were very similar and said things like ”I have already answered this in an other question”

23. Transcripts returned -*Were transcripts returned to participants for comment and/or correction?*
No

Domain 3: analysis and findings
Data analysis
24. Number of data coders -*How many data coders coded the data?*
Two

25. Description of the coding tree
Did authors provide a description of the coding tree?
No

26. Derivation of themes -*Were themes identified in advance or derived from the data?*
Mostly identified in advance, in categories of things important for the study’s research questions.

27. Software -*What software, if applicable, was used to manage the data?*
None

28. Participant checking -*Did participants provide feedback on the findings?*
No

Reporting

29. Quotations presented -*Were participant quotations presented to illustrate the themes / findings? Was each quotation identified? e.g. participant number*
No, quotations were not presented to illustrate themes and no individual participant were identified, the work load did not fit the scope of this study.

30. Data and findings consistent -*Was there consistency between the data presented and the findings?*
Yes

31. Clarity of major themes -*Were major themes clearly presented in the findings?*
Yes, the main categories of the themtisation was clearly stated.

32. Clarity of minor themes -*Is there a description of diverse cases or discussion of minor themes?*
The minor themes and nuances of opinions was not included in this study, simply because it could not fit within the scope.

Appendix IX. COREQ list for interviews with local people

Domain 1: Research team and reflexivity

Personal Characteristics

1. Interviewer/facilitator -*Which author/s conducted the interview or focus group?*
Andreas Särnberger, Lina Hammarstrand,

2. Credentials -*What were the researcher's credentials? E.g. PhD, MD*
M.Sc. students at Chalmers Technical University

3. Occupation -*What was their occupation at the time of the study?*
Students

4. Gender -*Was the researcher male or female?*
Andreas Särnberger – male
Lina Hammarstrand – female

5. Experience and training -*What experience or training did the researcher have?*
In qulitative analysis, no prior experience.

Relationship with participants

6. Relationship established -Was a relationship established prior to study commencement?
Only with one (out of four) of the interviewees who was also the wild life guide during the field assessments, though no relationship before the study began.

7. *Participant knowledge of the interviewer -What did the participants know about the researcher? e.g. personal goals, reasons for doing the research*
No villagers were had any knowledge of why the study was conducted.

8. *Interviewer characteristics -What characteristics were reported about the interviewer/facilitator? e.g. Bias, assumptions, reasons and interests in the research topic*
None apparent characteristics were reported.

Domain 2: study design

Theoretical framework

9. *Methodological orientation and Theory -What methodological orientation was stated to underpin the study? e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis*
This study was not a full-blown quliative analysis thus no methodology was fully used. Though a case study approach was chosen, in some ways similar to phenomoenology though with more of a contextual focus. Parameters such as accessability to the highway and that the two forests investigated were very close to each other but under different management schemes.

Theory Participant selection

10. Sampling -*How were participants selected? e.g. purposive, convenience, consecutive, snowball*
Purposive – Villagers were chosen because they had lived in the village for a long time and some were village elders and/or villagers who had central roles concerning the forest issues in the village.

11. Method of approach -*How were participants approached? e.g. face-to-face, telephone, mail, email*
Face-to-face

12. Sample size -*How many participants were in the study?*
Four villagers

13. Non-participation -*How many people refused to participate or dropped out? Reasons?*
No one refused or dropped out.

Setting
14. Setting of data collection -*Where was the data collected? e.g. home, clinic, workplace*
The villagers were interviews in their homes.

15. Presence of non-participants -Was anyone else present besides the participants and researchers?
One of the authors and two translators were present, the interview was conducted in Swahili through translators.

16. Description of sample -What are the important characteristics of the sample? e.g. demographic data, date
The villagers were chosen because of their knowledge of the forest and because of their position within the village hierarchy.

Data collection
17. Interview guide -Were questions, prompts, guides provided by the authors? Was it pilot tested?
It was a semi-structured interview, an over-all goal of the interview was given and open ended questions were used as a basis for the interview (both presented in the method chapter of the study)

18. Repeat interviews -Were repeat interviews carried out? If yes, how many?
No

19. Audio/visual recording -*Did the research use audio or visual recording to collect the data?*
No, due to technical difficulties the interviews with villagers were not recorded.

20. Field notes -*Were field notes made during and/or after the interview or focus group?*
Yes, on of the translators took notes while the second one lead the interview.

21. Duration -*What was the duration of the interviews or focus group?*
Around 30 minutes

22. Data saturation -*Was data saturation discussed?*
Interviewees were asked if they had anything to add. Some interviewees also noted that some questions were very similar and said things like ”I have already answered this in an other question”

23. Transcripts returned -*Were transcripts returned to participants for comment and/or correction?*
No

Domain 3: analysis and findings
Data analysis
24. Number of data coders -*How many data coders coded the data?*
Two

25. Description of the coding tree
Did authors provide a description of the coding tree?
No

26. Derivation of themes -*Were themes identified in advance or derived from the data?*
Mostly identified in advance, in categories of things important for the study’s research questions.

27. Software -*What software, if applicable, was used to manage the data?*
None

28. Participant checking -*Did participants provide feedback on the findings?*
No

Reporting
29. Quotations presented -*Were participant quotations presented to illustrate the themes / findings? Was each quotation identified? e.g. participant number*
No, quotations were not presented to illustrate themes and no individual participant were identified, the work load did not fit the scope of this study.

30. Data and findings consistent -*Was there consistency between the data presented and the findings?*
Yes

31. Clarity of major themes -*Were major themes clearly presented in the findings?*
Yes, the main categories of the themtisation was clearly stated.

32. Clarity of minor themes -*Is there a description of diverse cases or discussion of minor themes?*
The minor themes and nuances of opinions was not included in this study, simply because it could not fit within the scope.

Appendix X. GPS Coordinates for plots in field assessment

Table 6 GPS coordinates for plot locations in UTM format

Plot nr	Zone	Northing	Easting
1	37S	9263291	389116
2	37S	9263473	388915
3	37S	9263610	388675
4	37S	9263717	388446
5	37S	9263707	388335
6	37S	9263938	388075
7	37S	9264185	387890
8	37S	9263202	389498
9	37S	9263354	389329
10	37S	9263516	389167
11	37S	9263700	388973
12	37S	9263705	388879
13	37S	9263900	388739
14	37S	9264109	388498
15	37S	9264324	388283
16	37S	9263414	389829
17	37S	9263579	389639
18	37S	9263946	389264
19	37S	9264144	389058
20	37S	9264314	388933
21	37S	9263616	390162
22	37S	9263800	389958
23	37S	9263986	389750
24	37S	9264186	389563
25	37S	9264459	389291
26	37S	9264592	389158
27	37S	9264486	391409
28	37S	9264655	391232
29	37S	9264794	391048
30	37S	9264520	390959
31	37S	9271873	385667
32	37S	9271782	385786
33	37S	9271676	385901
34	37S	9271617	385983
35	37S	9271957	385790
36	37S	9271857	385904
37	37S	9271748	386005
38	37S	9271669	386132
39	37S	9272022	385859
40	37S	9271917	386033
41	37S	9271803	386198
42	37S	9272143	385954
43	37S	9272115	386067
44	37S	9272124	386251
45	37S	9272368	386197

46	37S	9272271	386275
47	37S	9272385	386283
48	37S	9272326	386356
49	37S	9264500	391850
50	37S	9264530	391900
51	37S	9264572	391846
52	37S	9264555	391945
53	37S	9264602	391896
54	37S	9264646	391859
55	37S	9264686	391825
56	37S	9264580	392000
57	37S	9264630	391955
58	37S	9264673	391915
59	37S	9264695	391870
60	37S	9264722	391828