Preliminary Assessment of Forest Structure, Management and Carbon Stocking in Tanzania Miombo Woodland

[1]Madoffe, S.S., [1]Rija, A.A., [1]Midtgaard, F., [1]Katani, J.Z., [1]Mbeyale, G., [1]Zahabu, E., [2]Liwenga, E., [3]Christopher, B.C.

[1]Sokoine University of Agriculture, [2]University of Dar-es-Salaam, [3]Aridhi University

Abstract

Wildfires are critical in miombo forests across the African continent causing loss of biodiversity, human properties and increasing climate change impacts. Within a broader project which seeks to develop a strategy to reduce wildfires in miombo woodlands of Tanzania, we report on the preliminary findings based on initial field data collected in situ to set a baseline for further work. The project covers three miombo biomes in three districts (Handeni, Kilosa and Kilwa) in Eastern Tanzania covering nine forest reserves managed under different authorities namely, central government, local districts and village communities. The aim of the current study were therefore, to describe species composition and structure of the forest communities, profile initial carbon stock in trees, herbaceous layer and soil within permanent survey plots, in effort to examine the potential of using fire reduction strategy as a potential tool of carbon sequestration in miombo woodlands.. The research team used permanent forest plots to collect vegetation and soil data. Simlarly available models were used to estimate carbon stocking. More than 200 species of trees and shrubs totaling 506 individual trees (dbh >4 cm) were recorded and Kilosa site contributed the largest proportion (40.7%) to the tree abundance total. This was followed closely by Kilwa (35.6%) and Handeni (20.7%). Species richness and diversity varied considerably within and between the study sites. Kilwa had the highest species richness and Handeni the lowest. Analysis of community assemblages revealed strongly distinct forest communities both at local and regional level between Kilwa and other sites. Carbon stocks in trees and soil were significantly different among sites and were higher than previously reported for other miombo woodland elsewhere in Tanzania. On the average tree carbon ranged from 21.42-44.12t/ha, the highest stock reported in Kilosa site due to assemblage of large trees. The general picture of carbon stock indicated that early burning is better for carbon storage than late burning or no burning. The lack of fire reduction strategy overrides the dynamics of forest stand structure and the potential for carbon sequestration by these forests as wildfires appear to be critical across the study area. There is dire need for a comprehensive strategy to reducing forest fires across the miombo biomes which together will help mitigate climate change impacts in Tanzania.

Key words: *Miombo woodlands, diversity index, community assemblage, fire reduction strategy, carbon sequestration, Tanzania*

1.0   Introduction

Savannas are the most extensive vegetation formation covering tropical Africa (Campbell, 1996; Osborne, 2000), the most common formation being miombo woodlands (Campbell *et al.*, 1996; Frost, 1996), with "75mi rural people and 20mi urban dwellers relying on miombo for their livelihoods" (Campbell *et al.*, 2008). In Tanzania miombo woodlands are the dominant forest component (Mutanga, 2009) whereas forests and woodlands are approximated to cover about 40% of the total land area (MNRT, 2001). Fire is known to be an important component of miombo ecosystems (Osborne, 2000; Kikula, 1986) and it is widely used by surrounding settlements as a tool for production and management among other reasons. In Tanzania wild land fire are human triggered particularly during farm preparations, hunting, honey collection, charcoaling and pastoralists.

The main effects of fires on forests are losses in stocks of biomass, change in hydrological cycle and nutrients (Salati and Vosep, 1984) and impoverishment of native plants and animal communities, which may be followed by biological invasions (Mueller-Dombois, 2001). Further, fire has a significant effect on climate change as it facilitates the release of carbon and other greenhouse gases (GHGs) to the atmosphere and destroys biomass thus limiting its role as a carbon sink. It is estimated that 20-25% of current annual carbon emissions are the result of loss of tropical forests (IPCC, 2000), part of this loss being contributed by wild land fires.

Fire occurs in most parts of the miombo woodlands and in most districts of Tanzania (Aloo 2001), and there are no apparent solutions to the fire problem. Despite years of regulation and attempts to control, and in most areas, fire incidence is believed to be increasing. Several efforts have been done in Tanzania to reduce fire frequency in miombo woodlands but the success has been constrained with lack of funds and/or proper strategies. In recent years, fire has compromised efforts towards forest sustainability and biodiversity conservation causing great concerns among government authorities, and local and international researchers and conservation agents. In spite of that, little is known on the place of fire in the society in terms of what triggers the setting of fire and whether there are traditional institutions governing the use of fire. The establishment and documentation of policies and procedures for fire occurrence at village to national levels will help villagers in the planning process to combating fire. Understanding of the fire regimes and the effects to the vegetation under different management scenarios can help to develop fire management strategies that will serve as a tool for carbon storage and sequestration in the miombo ecosystem. One of the available tools is

controlled burning. In this context, effects of early and late burning are important. The envisaged strategy will enhance in the establishment of an effective and functional National Fire Reduction strategy in Tanzania. This paper presents and discusses findings based on preliminary assessment of forest structure, management and carbon stocking in Tanzania miombo woodland in effort to examine the potential of using fire reduction strategy as a potential tool of carbon sequestration in miombo woodlands. The socio-economic data related to fire occurrence in the studied miombo woodland will be presented in another paper.

2.0 Methodology
2.1 Sampling design and data collection:

The current study was done in three districts namely Handeni, Kilosa and Kilwa and the choice was based due to availability of miombo, annual fire incidences and different management regimes therein. In each district three forests (Blocks) one under Central government (CG) management, Local (LG) government, and Village government (VG) were selected for the study. In each block, three plots each were established to assess the effect of fire on vegetation and natural regeneration in miombo woodland. In each block the plots were as follow: main plots (28x28 m); subplots plots (7x7 m); sub-sub plots (3.5x3.5 m). A 30m strip separated the main plots and fire lines of 4 m width were constructed to surround each main plot. Three treatments namely; early burning (EB), late burning (LB) and no burning (NB) (control) were considered in this study. Experimental early burning was conducted in July for all the sites and late burning in September.

In the main plots all trees with dbh ≥10 cm were measured for stem dbh and height for one large tree, one medium tree and one small tree. In each main plots, four sub-

plots (7x7m) were constructed and data on tree abundance, stem dbh and height for all trees with dbh 10< and 4≥ recorded and grasses and herbs harvested for determining biomass (i.e. carbon stock). Two sub-sub-plots (3.5x3.5m) in each four sub-plots were randomly selected and measured for abundance and stem height for all trees/shrubs and seedlings with dbh <4cm. Also percentage area covers of herbaceous and grasses were recorded. All plant species in the main plots, sub-plots and sub-sub-plots were also recorded and identified. Surface soil samples (0-5 cm depth) were taken at the four corners and from the center, i.e. from each four sub-plots (7x7m) of the main plots and mixed to form a composite sample and packed in a plastic bag and labelled for laboratory analysis. Data collection in subsequent years (year 2 and 3) is expected to reveal the impact of fire to the miombo vegetation; The socio-economic information related to fire in the study area is not presented here.

2.2   Data analysis:

Vegetation data: The allometric equation developed by Malimbwi *et al.,* (2005) for the miombo woodlands was used to compute forest stocking parameters as average sums of trees in the plots.

$$V = 0.000011972D^{3.191672}$$

Where V = tree volume (m3) and
D = tree dbh (cm)
(R^2 = 0.98)

For biomass estimation an allometic equation developed by Chamshama *et al*., (2004) was employed. This equation includes trees from 1 cm diameter at breast height (dbh) and it has the advantage of requiring only dbh as a variable. It also had R^2 of 97% making it reliable for the estimation of biomass. The equation is:

$$Biomass = 0.0625D^{2.553}$$

Where: $Biomass$ = total tree biomass (kg/ha) and
D = tree dbh (cm)

The biomass was then converted to carbon using a biomass-carbon ratio of 0.49 (MacDicken, 1997; Brown, 1997; Brown, 2003).

Carbon = Biomass X 0.49

To get equivalent atmospheric CO_2, the stock values were multiply by 3.67 since a gram of pure carbon is equivalent to about 3.67 grams of CO_2. Analysis of Variance (ANOVA) was done to compare the study variables between different management scenarios, burning regimes and between districts.

Samples for shrubs and grasses from each plot were oven-dried to determine dry-to-wet matter ratios. The results was averaged for all the samples taken, to give a per square meter estimate of non-woody biomass. Soil and organic carbon (standing and dead litter biomass) was analyzed in the laboratory at Sokoine University of Agriculture for each study site. The significant difference in carbon stock in trees, soil and grass biomass among study sites was tested using Kruskal Wallis test. A correlation test was done between species diversity and forest carbon stock to examine relationships between the variables. On the other hand species diversity was assessed with the Shannon-Wiener index (Magurran, 1988):

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

Where P_i is the relative frequency of the ith species.

Species richness was estimated according to the Margalef index (Ludwig and Reynolds, 1988):

$$R_1 = \frac{S-1}{\ln N}$$

Where S is the total number of species and N is the total number of individuals.

3. Results

3.1 Species composition and structure of miombo forest in the study area

More than 200 species of trees and shrubs totaling 572 individual trees (dbh >4 cm) were enumerated in the three study sites during the initial sampling period. At a regional level (spatial) Kilosa site contributed the largest proportion (40.7%) to the tree abundance total. This was followed closely by Kilwa (35.6%) and Handeni (20.7%). There were local differences in tree abundance in the surveyed plots. Within Kilwa site, trees were numerically significantly high in number at Kikole village forests (61.7%, n = 111) than in Mitundumbeya (6.1%, n = 11) and Mitalule (32.2%, n = 58) both managed under the local and central governments authorities respectively. However, such a trend was less evident on

survey plots in Handeni and Kilosa miombo forests. Species richness was on the average, higher (2.87) in Kilwa (range 1.99 – 3.55) than Kilosa forest (range 1.79 – 2.74) and was lowest in Handeni forests (range 1.73 – 2.24) (Table 1). Species richness was different in the forest communities under different management regimes. In Kilwa, species richness was higher in community-based managed forests (Kikole, 3.55) and lowest in forest managed under the central government (Mitalule, 1.99). Unlike Kilwa, the forests under the central government in Handeni and Kilosa recorded highest species richness while the richness was nearly twice as much higher in village community forests in Kilosa than Handeni district plots (Table 1). Dominant species also varied in all the study sites and forests.

Table 1. Species richness and diversity and the dominant species in the forest communities under different management authorities

District	Study Forest	Margalef's Sp richness	Shannon div. index	Dominant species
Handeni	Gumba VLFR	2.048	1.689	*Combretum zeyheri*
	Kiva hill CGFR	2.236	1.586	*Kigelia africana*
	Handeni Hill LAFR	1.726	1.234	*Maesa lanceolata*
Kilosa	Palaulanga CGFR	2.737	2.017	*Pseudolachnostylis glauca*
	Mbilili VLFR	1.797	1.504	*Chassalia albiflora*
	Magubike South LAFR	2.613	1.915	*Brachystegia spiciformis*
Kilwa	Mitundumbeya LAFR	3.074	2.087	*A.senegalensis, P.glauca*
	Mitalule CGFR	1.999	1.637	*Acacia sp*
	Kikole VLFR	3.545	2.31	*Pseudolachnostylis sp, E. candelabrum*

VLFR = village forest reserve, CGFR = Central government forest reserve, LAFR = Local government forest reserve.

Species diversity also varied considerably within and between the study sites. Shannon diversity index was significantly different between the forest types in Kilwa i.e. between Mitundumbeya, Kikole and Mitalule study locations (ANOVA, F = 5.221; df = 2; P = 0.049) with Kikole

contributing highest to species diversity (H' = 2.31). Neither Handeni (F = 0.432, df = 2; p = 0.667) nor Kilosa (F = 2.54; df = 2; p = 0.159) showed significant variations in species diversity (Figure 1). However there was a non-significant trend in regional differences in species diversity

among the study sites (ANOVA, F = 3.281; df = 2; P = 0.055) with Kilwa contributing significantly to the observed regional variations (H' = 2.87) (Figure 2)

Diameter of trees (>10 cm) was significantly different among Kilosa forest types (Kruskal Wallis χ^2 = 23.438, df = 2; p = 0.001) with Palaulanga forest recording largest median diameter (median dbh = 47 cm). Differences were also observed among Kilwa forest types (Kruskal Wallis χ^2 = 12.487, df = 2; p =

0.002; Mitundumbeya and Mitalule forests, median tree diameter = 30 cm) and among Handeni forest types (Kruskal Wallis χ^2 = 25.686, df = 2; p = 0.001; Gumba forest median tree diameter = 27 cm). Moreover, tree diameter was significantly different (Kruskal Wallis χ^2 = 8.994, df = 2; p = 0.011; median dbh = 17.6 cm) across the study sites with trees in Kilosa miombo forest showing overall largest median diameter at breast height (median dbh= 105 cm).
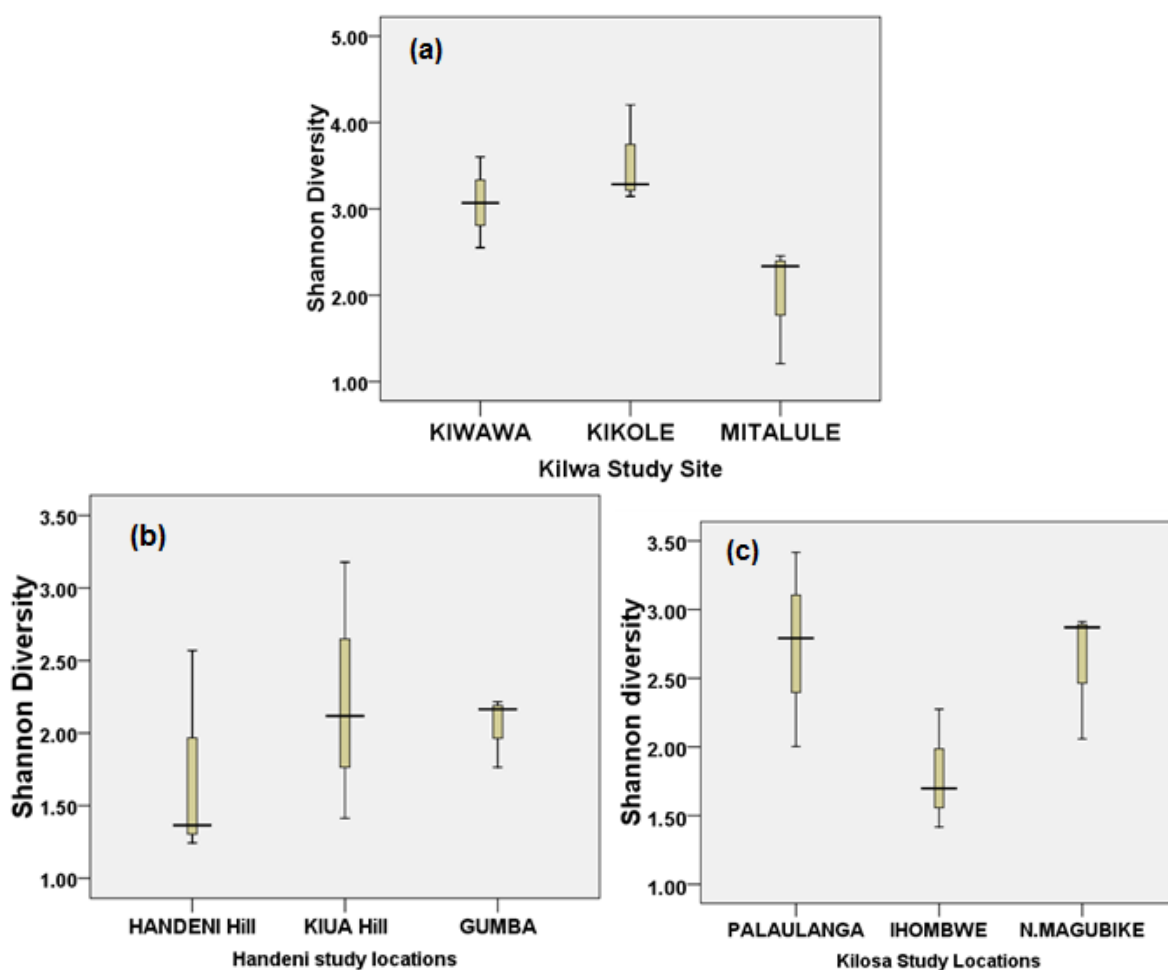

Figure 1. **Species diversity in forest localities in the three study sites. Shannon diversity index was significantly different between forest types in Kilwa (a) but not in Handeni (b) and Kilosa (c). See text for test statistics.**
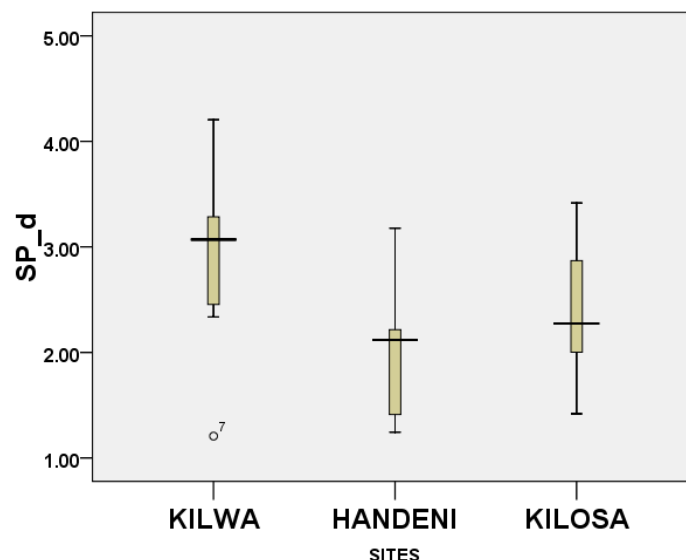
Figure 2. Species diversity across the three study sites (spatial differences). There was an almost significant difference between Kilwa & Handeni study areas (F = 3.281; p = 0.055).

3.2 Assemblages of forest communities in the study area

A non-metric multidimensional scaling (NMDS) of the tree samples from the study sites is shown in Figure 3a. The SIMPROF test performed under cluster analysis indicated internal structuring of the forest communities among study localities (Pi = 2.52; p = 0.1%). One way analysis of similarity (ANOSIM) also showed strongly distinct assemblages of forest communities across the study sites (Global R = 0.673, p = 0.1%; Figure 3b). The assemblages were particularly different between Kilosa and Kilwa (Global R = 0.802, p = 0.1%) and between Kilwa and Handeni (Global R = 0.85, p = 0.1%) but less so between Kilosa and Handeni (Global R = 0.312, p = 0.1%).

Further, analysis of similarity percentages (SIMPER) of forest communities between localities indicated the surveyed forest communities in Kilwa were similar for only 27.79 % while Kilosa forest communities were similar for 17.35% and Handeni, 26.41%. Further examination of species contribution to the observed assemblages showed considerable differences between and among forest communities in the study area. *Pseudolachnostylis glauca* was the dominant tree species in Kilwa (contribution, 27.85%) and contributed most (7.13%; average dissimilarity 6.98 ± 1.39) to the observed average dissimilarity between Kilwa and Kilosa community assemblages (97.92%). The dominant species in Handeni was *Combretum molle* (contribution, 25.89%) while *Brachystegia spiciformis* dominated in Kilosa forest communities (contribution, 30.64%). On the contrary, the average dissimilarity between Kilwa and Handeni forest community assemblages (91.62%) was due to *Brachystegia spiciformis* which had an average contribution of 6.80% (Average dissimilarity 6.23 ± 1.46) over other species in the study area.
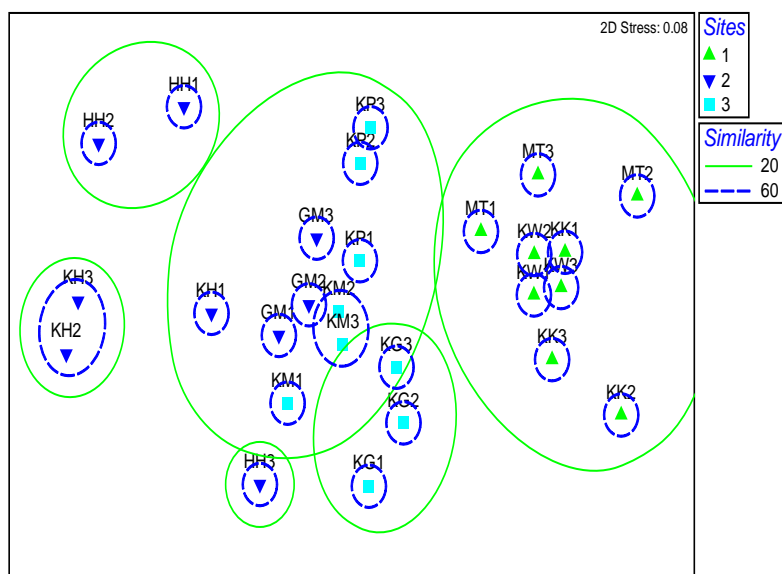
Figure 3a. Similarity among forest communities in the study areas, Kilwa (1), Kilosa (2) and Handeni (3).
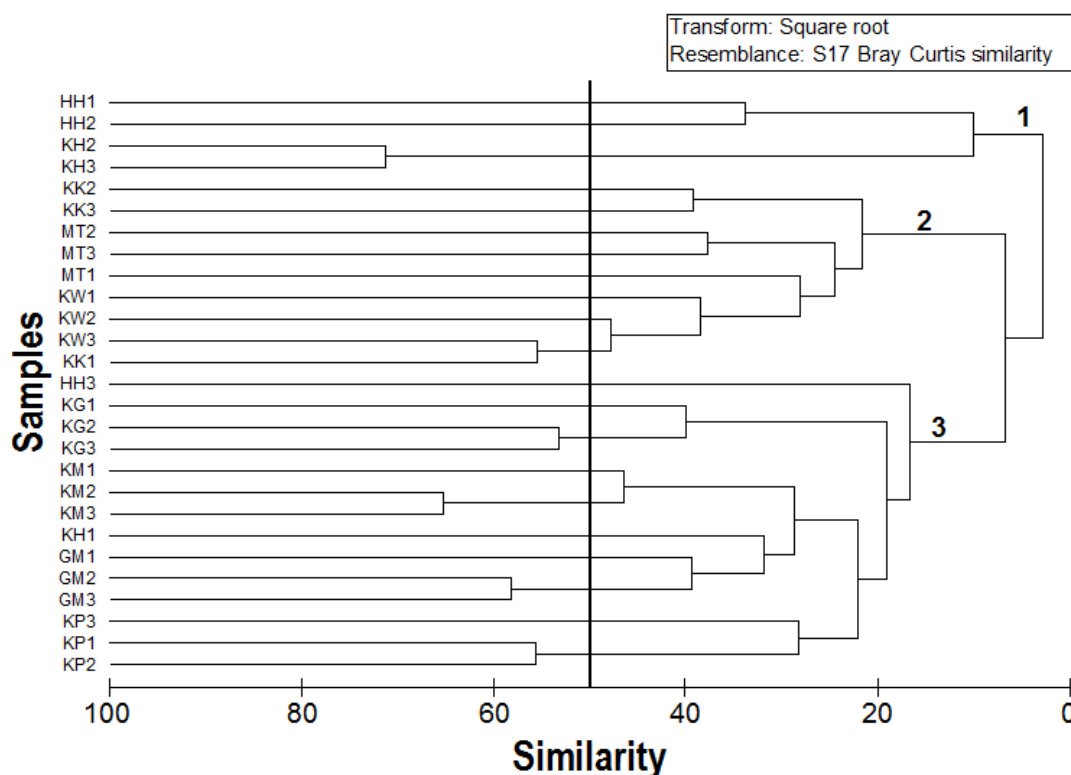

Figure 3b. Assemblages of the study forests showing distinct forest communities; 1, 2, and 3 based on Bray –Curtis similarity of the samples as analyzed under program PIMER v6. There were clear structuring of the species in samples from across the study sites, Kilwa, Kilosa and Handeni (Global R = 0.673, p = 0.1%, see text for details).

3.3 Initial carbon stocking in trees, soil and grass biomass

Initial carbon stocking in trees, soil and grass biomass varied among and between sites (Table 2). Across the study area, there were no significant differences in tree carbon stocks among trees of dbh>4<10 cm (Kruskal Wallis $\chi^2 = 2.98$, df = 2; p = 0.255) or trees dbh $\geq$10 cm (Kruskal Wallis $\chi^2 = 1.689$, df = 2; p = 0.430). However, there was significant difference of carbon stock in trees between the two diameter classes (Wilcoxon W = 45.0, Z = -3.578, p = 0.001). Analysis of the grass

biomass carbon by loss in ignition method indicated differences among local forests in Kilwa (ANOVA, F = 6.102, df = 2, p = 0.006). Multiple comparison with a Sidak post-hoc test revealed differences was only between Kikole and Mitundumbeya forest reserves (p = 0.004) which are managed under the village and district government authorities respectively. Soil carbon showed similar pattern (F = 4.734; df = 2; p = 0.056) all across the forest reserves in Kilwa. Also, soil carbon content of the

surveyed plots indicated significant differences between the study sites in the three districts (ANOVA, F = 125.565, df = 2, p = 0.0001) with the difference occurring among all sites. The general picture from Table 2 is that early burning is better for carbon storage than late burning or no burning. The only exception being Handeni, but the result here might be caused by the late burning plot only consisting of large trees.

Table 2. Initial carbon content in trees and soil at the study locations and sites that will form a basis for subsequent monitoring at the experimental plots

Study forest sites	Tree carbon in tree size classes and burning regime			Soil carbon	
Kilwa	Fire regime	d<4>10 cm	d≥10 cm	Total C(t/ha)	Mean soil C (SD)	Range
	Early burning*	0.92	33.08	34	2.408 ± 0.946	0.90 - 5.48
	Late burning*	0.76	20.98	21.72		
	No burning*	0.67	27.7	28.36		
Handeni	Early burning*	0.37	21.06	21.43	5.438 ± 1.315	2.48 - 8.75
	Late burning*	0	24.71	24.71		
	No burning*	0.07	18.83	18.91		
Kilosa	Early burning*	0.18	44.73	44.92	7.311 ± 1.638	4.44 - 10. 9
	Late burning*	1.23	22.23	23.37		
	No burning*	0	22.09	22.09		

*This indicates initial data profiles at the beginning of the field experimental treatments. These data will be referred to as benchmark in subsequent burning treatments over the period of the research project.

4.0   Discussion
This study documents composition and structure as well as carbon stocking of miombo forests under different management regimes based on initial data collected *in situ.* Ours is the first study describing community assemblages of miombo woodland in East and north–eastern Tanzania that receive varying management efforts.

4.1 Tree species and community structure of the miombo woodland
The number of tree species recorded for this study was higher than previously recorded for other miombo forests elsewhere in Tanzania (Chamshama *et al*., 2004; Shirima *et al*., 2011; Zahabu, 2008). We enumerated more than 200 species

while these studies recorded less than 100 species although all studies included trees > 4 cm DBH. The difference between the current study and these studies could be due to high forest productivity in the moist coastal region as opposed to the hinterland forest communities. Further, species composition of the surveyed forests depicted regional variation between Kilosa and other sites (Handeni and Kilwa). Perhaps this was attributable to different levels of forest disturbances these forests are being subjected to (Banda *et al*. 2006). Kilosa in particular recorded highest level of forest disturbances such as livestock grazing, wildfires and logging corroborating with previous findings in this area (Backeus *et al*., 2006). However, the forest showed secondary

regeneration with lots of trees regenerating after disturbances. Further, the disturbances recorded (particularly due to fires and trees or pole cutting) in the study sites also may in part indicate different management inputs under which these forests are given by different authorities. There was generally high level of forest disturbances in the forests managed by the local government followed by those under central government.

The Shannon diversity index of the study forests indicates that all the forest communities are relatively diverse in tree species compared with other miombo forests in the lowland and Eastern Arc mountains forests (Luoga 2000; Pare´ 2008; Shirima et al. 2011). The spatial differences in species composition and diversity among study sites could be due to geographic locations of individual forests and land use history (Mapaure, 2001; Chidumayo, 2002). Kilwa recorded highest tree diversity (Shannon index = 2.011 over Handeni and Kilosa, 1.503, 1.812) perhaps because of environmental and edaphic factors influenced by coastal climates leading to high productivity in coastal forest than is in other areas (Backeus *et al.*, 2006; Haddad *et al.*, 2008). The local variations in species diversity between forest communities within Kilosa and Handeni study sites were attributable to local differences in disturbance regimes as has been explained by an intermediate disturbance hypothesis which indicates that habitat disturbance influences species diversity more in dry than in moist forests (Bangor *et al.*, 2009). Both Handeni and Kilosa forest communities had many trees of the genera *Combretum, Kigelia, Chassalia, Markhamia, Pseudolachnostylis*, and *Syzygium* whose presence indicate disturbance and hydrological influences (Backeus *et al.* 2006; Banda et al. 2006). Although species diversity increases at intermediate level of disturbance (Haddad *et al.* 2008), this cannot explain the

variation of species diversity among the humid forest communities in Kilwa District where disturbances were very minimal, rather could be a reflection of local variability in plant water availability due to environmental factors such as soil fertility, topography and local hydrology acting to shape the functional dynamics of the forest communities (Oksanen & Minchin 2002; Sheil & Burslem 2003; ter Steege *et al.* 2006). Also these factors may partly explain the observed internal structuring of forest communities among study localities. Similarly these local assemblages could be caused by differing management regimes by the central, local and village governing bodies. Further, there were strongly distinct forest communities between the study sites depicting differences between Kilwa and Kilosa or Handeni. Contributed by different species, these assemblages may be due to spatial variability in rainfall pattern, soil nutrient dynamics and local dynamics of plant communities between the sites.

4.2 Carbon stocking in miombo forests

The carbon content of the standing tree biomass was lower in young than in old trees (> 10 cm dbh) because the rate of carbon accumulation increases with the growth stage of the plants (Amichev *et al.*, 2008). Also, our data indicated spatial and local variability in carbon storage amongst the study forests reserves because of variation in growth forms, as well as species composition and abundance (Table 4). Kilosa contributed highest to the tree abundance total with most of the trees in the reserves having a dbh of > 10 cm, thus resulting in higher carbon stored in Kilosa than other forest sites in Kilwa and Handeni. The range of carbon stored in trees (21.42 – 44.92 t/ha) in the study forest reserves is higher than the range reported previously for miombo woodland in the Eastern Arc mountains (13 – 30 Mg C/ha, Shirima *et al.*, 2011) as well as for

the southern highland miombo forests (17.9 – 20.4 t/ha, Munishi *et al*., 2010). However, this range was lower than published for afromontane forests in the Eastern Arc Mountains (Munishi & Shear, 2004). Further, the differences in carbon estimates of the soil samples among study sites were due to variability in local environmental factors such as soil nutrient dynamics as well as rainfall pattern.

Differences in ecology and the reasons why people lit fires in the different regions will be addressed in a future article.

5.0 Conclusion

This study reports preliminary findings of a big research project based on initial data available during the first phase of data collection in the field. We have described the structure and composition as well as initial carbon stocks of forest reserves under different management authorities. The forest reserves are diverse and comprise of distinct forest communities due to various species assemblages in them. The data reported here will be used as benchmark to monitor the variability in carbon stocking on study plots set out in Kilwa, Handeni and Kilosa forest reserves where burning treatments will be performed and monitored over the three years in order to develop a strategy to reducing wildfires in miombo woodlands of Tanzania. Preliminarily, it is however, concluded that:

- There were local differences in tree abundance in the surveyed plots and more than 200 different species of trees and shrubs were recorded and Kilosa site contributed to the largest proportion (40.7%) of the tree abundance total, followe by Kilwa and Handeni each contributing (35.6%) and (20.7%)

- Species richness and diversity varied considerably within and between the study sites, Kilwa and the village forests giving the highest species richness and diversity

- On the average carbon content of the standing tree biomass was lower in young than in old trees. Similarly there is an indication that village forests have higher stock of carbon than the central government and local government forests.

- On the average early burning is better for carbon storage than late burning or no burning

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