academicJournals

Vol. 6(3), pp. 230-237, March 2014
DOI: 10.5897/IJBC2013.0671
ISSN 2141-243X © 2014 Academic Journals
http://www.academicjournals.org/IJBC

International Journal of Biodiversity and Conservation

*Full Length Research Paper*

# Woodlands degradation in the Southern Highlands, Miombo of Tanzania: Implications on conservation and carbon stocks

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Accepted 5 February, 2014

**Miombo woodlands is one of the major forest vegetation types covering about two thirds of the country forest land and form an integral part of the rural landscape in Tanzania, also they play crucial role in providing wide range of ecosystem services including carbon sequestration. This study aimed at assessing the effects of degradation on the structure and carbon stocks of miombo woodlands. Data were collected from 50 rectangular plots measuring 40×20 m. Stump diameter, diameter at breast height, tree height and species local and botanical names were recorded. Analysis was done by using R software and excel spread sheet. Results showed total harvesting of 10.53 $m^3ha^{-1}$ as compared to standing volume of 32.6 ± 2.3 $m^3ha^{-1}$ with basal area of 4.73 ± 0.5 $m^2ha^{-1}$. Estimated annual harvesting was found to be 6.63 ± 3.0 $m^3$ $ha^{-1}$ which exceeds mean miombo annual increment of 4.35 $m^3$ $ha^{-1}$ $year^1$, this is indicator for unsustainable utilization which could results into woodland change. Harvesting resulted into total loss of 4.1±0.9 $tCha^{-1}$ equivalent to 15.05 ± 3.3 $tCO_2eha,^{-1}$ new harvesting presenting 9.91 $tCO_2e$ $ha^{-1}$ and old 5.14 $tCO_2eha^{-1}$. Managing the miombo woodlands carbon stocks for emissions and climate change mitigation in Tanzania and elsewhere requires rigorous effort to reduce anthropogenic degradation.**

**Key words:** Carbon emissions, climate change, Miombo woodlands, degradation.

## INTRODUCTION

Deforestation[1] and forest degradation[2] are estimated to account for about 20% of global anthropogenic $CO_2$ emissions through combustion of forest biomass and decomposition of remaining plant material and soil carbon (Van der Werf et al., 2009). Rate of deforestation and degradation has been significantly compounded by the need for land to be used for settlement, agriculture and energy (wood-fuel and charcoal), the development of infrastructure, particularly roads and the provision of water, are major contributing factors (Bond et al., 2010)

Tanzania has a total area of about 94.5 million ha out of which 88.6 million ha is covered by landmass and the rest is inland water. Forests in Tanzania cover about 34 million hectares making about 40% of total land. The total forest area can be divided into a number of different ecological forest types. According to the WWF ecoregion

[1] Deforestation involves the conversion of forested areas to non-forest land use such as arable land, rural settlements, urban use, logged area or wasteland.
[2] Degradation is considered as changes that take place in the forests or woodland which negatively affects its structure, function or both and thereby lower the capacity to supply products and or services.

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classification of Burgess and Clarke (2000), miombo woodlands is the dominant vegetation type covering about 95% of total forest area (MNRT, 2006). Rate of deforestation and degradation in Tanzania is estimated to be 403,000 ha/year equivalent to 1.13% (FAO, 2010). It is therefore logical to link the high rate of deforestation and degradation to be impacted on the miombo woodlands because of its wide distribution in the country.

Degraded forest, woodlands and secondary[3] forests cover significant areas in the tropics. In fact in most countries they now exceed areas covered by primary[4] forests (FAO, 2005). It is estimated that, during the 1990s, 16.1 million ha of forests was lost globally each year due to deforestation, of which 15.2 million ha was lost in the tropics (Achard et al., 2004; FAO, 2005). This corresponds to annual forest losses of 0.4% globally and 0.8% in the tropics. The root causes underlying these changes are complex combination of the interrelated factors that include population growth (Peacrce and Brown, 1994; Bawa and Dayanandan, 1997), economic growth and household resource consumption (Lui et al., 2003), poverty (Naughton et al., 2011) and land tenure insecurity (Gardner-Outlaw and Engelman, 1997). These trends of deforestation signify that a greater proportion of the world's primary forest will be replaced by secondary and degraded forests.

Miombo is a vernacular word that has been adopted by ecologists to describe those woodlands dominated by trees in the genera *Brachystegia, Julbernadia* and *Isoberlinia* (Leguminosae, sub-family Caeasalpinioideae) (Abdallah and Monela, 2007). They cover between 2.7 and 3.6 million km$^2$ in 11 countries in Africa although it is the dominant vegetation in the region it is by no means the only ecosystem, nor is it equally distributed across the 11 countries. To the rural poor, miombo woodlands are a valuable resource (Chidumayo, 1993). They provide an effective safety net in times of distress and stress. However, many urban residents also use a range of goods from the woodlands, such as fuel wood, charcoal, fruits and fungi and there is a steady flow of goods and services between rural and urban areas (Bond et al., 2010).

Despite the miombo woodlands wide coverage, focus on deforestation and degradation has tended to be on those major tropical forest and less substantial attention paid to the miombo woodlands where the per unit area of carbon stocks are lower than tropical forests (Bond et al., 2010). Climate change mitigation initiatives resulting from the United Nations Framework Convention on Climate change are now managing tropical woodlands to sequester carbon (Silver et al., 2004). Miombo are likely to have high potential for carbon storage and mitigation of carbon dioxide emissions due to its dominance (Grace et al., 2006, Williams et al., 2008) however they have been undergoing severe degradation due to various uses which results in carbon dioxide emissions. Tanzania being one of the nine pilot countries undertaking Reduced Emissions from Degradation and Deforestation (REDD+) initiatives is supposed to calculate its forest and woodlands area, rates of deforestation and degradation, which will act as baseline information of emission levels. This study was conducted in Chunya district, whereby about 4% of the total land is dominated by miombo woodlands which are major source of woodfuel in Mbeya region (URT, 1997). Increasingly need for woodfuel especially in township and agricultural expansion activities due to population increase has resulted in unsustainable utilization of dominating miombo ecosystems and carbon dioxide ($Co_2$) emission. Therefore, this paper aims at investigating extent of $Co_2$ emission resulting from extensive utilization of miombo woodlands by quantifying harvesting intensity from the stumps.

[3] Primary forest refers to those forest occurring in areas which has never been invaded by human activities such as agriculture

[4] Secondary forests occurs in areas which has been under disturbance e.g. cleared for shifting cultivation

## MATERIALS AND METHODS

### Study sites

Chunya District is located in the North - Western part of Mbeya Region. The district is among seven (7) districts of Mbeya region and it is located at 8° 32' 07" S 33° 27' 37" E. The District is bordered by Singida and Tabora regions to the north; Iringa region and Mbarali districts to the East; Mbozi and Mbeya districts to the South; Rukwa region and Lake Rukwa to the West. It is the biggest district as compared to others in the region occupying a total area of 29,219,000 ha (46% area of Mbeya region). The land area is classified into different uses including arable land occupying 3,005,000 ha (78.73%), game reserves 2,000,000 ha (6.85%), forest reserves 396,400 ha (1.36%), water bodies 1,505,000 ha (3.78%) and the other uses 2,712,600 ha (9.28%) (URT, 1997). Predominant natural vegetation is miombo woodlands, with vast areas in Kwimba and Kipembawe Divisions. Data were collected in Manga reserve, in Chokaa Division (Figure 1), the reserve is domi-nated by miombo species *Brachystegi, Julbernadia* and *Isoberhinia* species (MFMP, 2008). It covers a total area of 9830 ha under community forest management (CBFM). According to Manga Forest Management Plan (2008), the forest is divided into utilization zone which is South of Mwashiwangu River with controlled utilization through the issuing of licences and conservation zone to the north of Mwashiwangu River. However, utilization pattern do not conform to agreed conditions (Chunya Socio Economic Profile, 1997).

### Data collection

Forest inventory with systematic sampling design was used. The Number of plots were calculated after determination of study area variations whereby 50 plots were laid out. Rectangular plots of 40 × 20 m were used as they are more efficient in heterogeneous area as compared to circular plots (Goslee, 2006; Stohlgren, 1995). Within plots all trees with diameter at breast height (DBH) > = 5 cm, basal diameter of the stumps were measured. The minimum diameter was selected because smaller trees are not resistant to annual fires in miombo woodlands Kielland-Lund (1990b) as cited by Luoga et al. (2001). Other data collected include species name

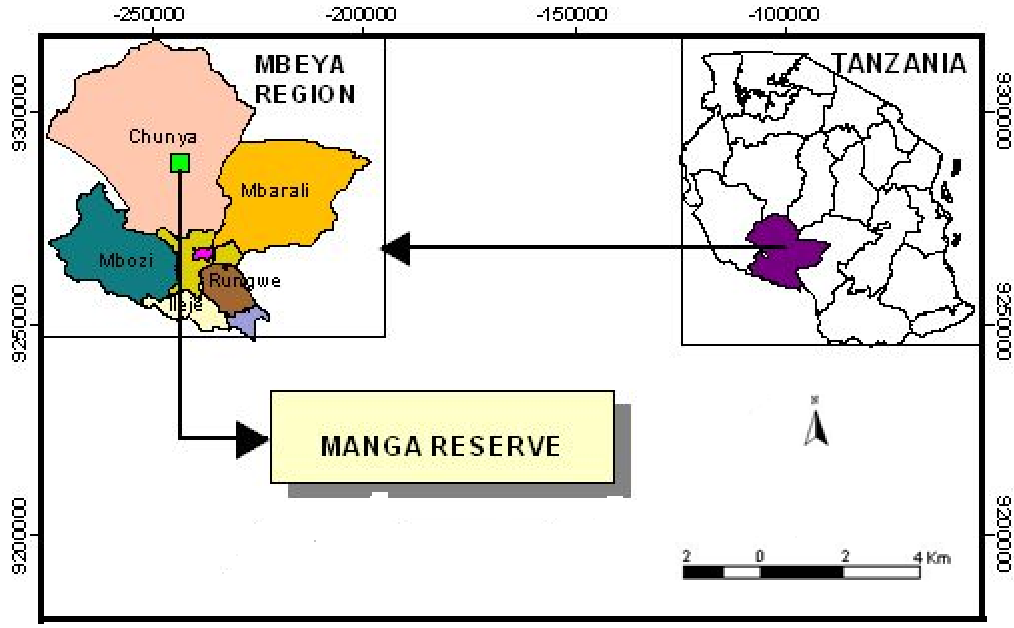


**Figure 1.** Map showing study site within Tanzania.

for all trees, shrubs and age of stumps since harvesting, which was decided to be either new or old. The distinction between old[5] and new[6] stumps was established by the colour and freshness of the exposed wood, the size of the sprouts/coppices and the presence of fire scorch on exposed wood. Identification of stumps age and naming was done with the aid of local elders well acquainted with ethnobotany and aspect of wood utilization. The criteria used for identification of the harvested species were coppice growth, wood and bark characteristics of the stump. Tree and shrub species were locally named by local botanist; botanical identification was made by matching local names with botanical names available in the literature. Three sample trees were measured from each plot (large, medium and small) which made a total of 150 trees from all plots. These trees were measured for stump diameter (bd), diameter at breast height (dbh) and total height (ht).

#### Data analysis

Tree volume for both removed and standing trees were calculated by multiplying tree basal area (g), height (h) and form factor (f) (Philips, 1994). The form factor of 0.5 for natural forest was used (Malimbwi and Mugasha, 2002). Biomass of the standing and removed trees were computed by multiplying tree volume with average wood basic density of 0.58 g/cm$^3$ (Malimbwi et al., 2000). Then tree carbon was obtained by multiplying biomass by 49% as a conversion factor for biomass to carbon (MacDicken, 1997). A factor of 3.67 $tCo_2$ per unit of C was used to convert obtained carbon to emissions (Zahabu, 2008). Diameter at breast height: (dbh) for removed trees was obtained by regressing dbh and stump diameter (bd) of sample trees, and the following equation was obtained:

Old[5] Harvested before 2010
New[6] Harvested within 2010

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

Height of removed trees was obtained by regressing height to basal diameter of sample trees, and the following equation was obtained:

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

## RESULTS

### Structure of Manga Miombo woodland

The average stem density (N; d ≥ 5 cm) was 232 stems ha$^{-1}$ with big variation between plots. The basal area (G) ranged from 2.4 to 7.9 m$^2$ ha$^{-1}$ with average of 4.73 m$^2$ ha$^{-1}$. Stand volume averaged 32.6 m$^3$ ha$^{-1}$. Diameter distribution of the stand resemble those of uneven aged stand with a constant reduction towards larger classes (Table 1 and Figure 2). The following general were dominant, *Brachystegia spiciformis, Pericopsis angolensis, Pterocarpus angolensis, Rhus natalensis* and *Lapotea ovalifolia.* On the other hand, it was noted that middle class diameter estimates more volume and basal area.

### Carbon storage and degradation in Miombo woodlands

Total above ground was estimated to be 10.6 t C ha$^{-1}$ which was contributed by different species found in Manga reserve, however *Brachystegia spiciformis*, *Pterocarpus angolensis* and *Pericopsis angolensis* were found to contribute 60.3% of total above ground carbon and 39.7% contributed by remaining 24 species (Table

**Table 1.** Stand characteristics of Miombo woodlands in Manga Reserve.

| Parameter | |
|---|---|
| Basal Area ($m^2$/ha) | 4.73 ±0.5 |
| Stem density (stems $ha^{-1}$) | 232±13 |
| Standing V ($m^3$ $ha^{-1}$) | 32.6±2.3 |
| Above Ground Biomass ($tha^{-1}$) | 21.7±1.6 |
| Above Ground Carbon ($tha^{-1}$) | 10.6±1.3 |

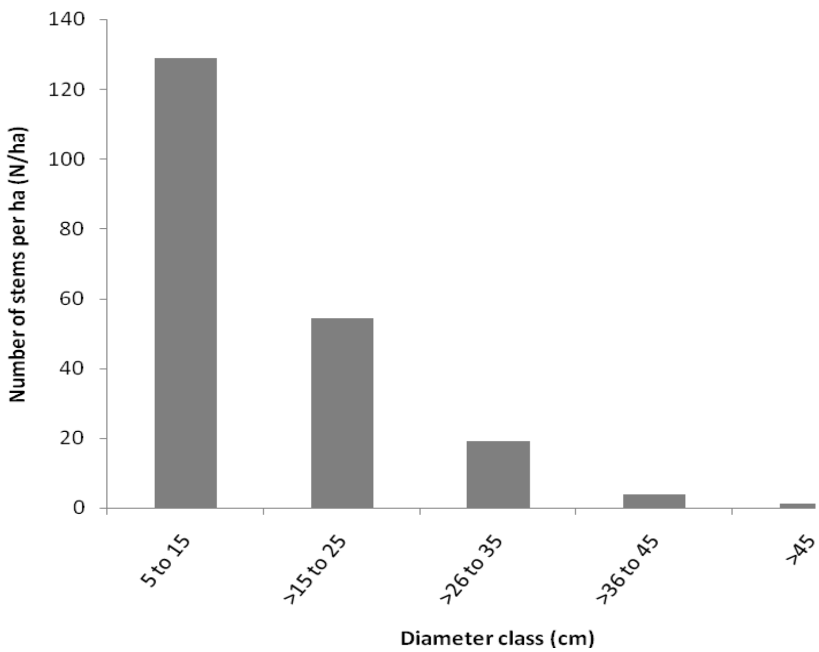


**Figure 2.** Number of stems distribution by diameter class in Manga reserve.

2). We estimated a total carbon loss of 4.1 $tCha^{-1}$ from 187 stumps of which majority were *B. spiciformis, Brachystegia boehmii* and *P. angolensis* contributing to 89.3% of total removal. The major activities contributing to wood removal were charcoal making (88.3%), timber harvesting (9.3%), poles, explosives and ropes (2.4%) (Tables 3 and 5).

## DISCUSSION

### Harvesting intensity

Tree removal represented a basal area of 1.53 ± 5.06 $m^2$ $ha^{-1}$ and an average volume of 10.53 ± 3.1 $m^3$ $ha^{-1}$. Similar study conducted by Luoga et al. (2001) in Kitulangalo forest reserve, reported harvested volume of 7.1 ± 1.2$m^3$ $ha^{-1}$ which is less as compared to results from this study; however he used bigger plot as compared to this study (Table 4). Majority of stumps were found to be new however it was noted that villagers uproot old stumps due to the easiness of uprooting as compared to new for agricultural land (shifting cultivation), this case is contrary to other studies whereby more stumps were recorded to be old (Luoga et al., 2001; Zahabu, 2008). On the other hand, it was observed that charcoal and timber were the major activities conducted in the forest contributing to 88.3 and 9.2% of total harvest respectively, other activities that were found to be practiced by villagers includes pole extraction, making explosives and ropes which fill the remaining percent. Luoga et al. (2001) reported from his study in Kitulangalo that only 0.5 and 54% of total harvesting was contributed by timber harvesting and charcoal, respectively. This shows that there is high demand for charcoal and timber in Mbeya town

**Table 2.** Biomass and carbon contribution by different species in Manga Forest Reserve, Tanzania.

| Scientific name | Biomass ($tha^{-1}$) | Carbon ($tha^{-1}$) | Percentage (%) |
|---|---|---|---|
| *Brachystegia spiciformis* | 7.786 | 3.893 | 36.3 |
| *Pterocarpus angolensis* | 3.846 | 1.923 | 17.9 |
| *Pericopsis angolensis* | 1.308 | 0.654 | 6.1 |
| *Rhus natalensis* | 1.184 | 0.592 | 5.5 |
| *Laportea ovalifolia* | 1.168 | 0.584 | 5.4 |
| *Crotularia grandibracteata* | 0.876 | 0.438 | 4.1 |
| *Pourtelia maprouneifolia* | 0.868 | 0.434 | 4 |
| *Ozoroa insignis* | 0.864 | 0.432 | 4 |
| *Brachystegia boehmii* | 0.824 | 0.412 | 3.8 |
| *Combretum molle* | 0.71 | 0.355 | 3.3 |
| *Pourtea adolfi* | 0.696 | 0.348 | 3.2 |
| *Vitex doniana* | 0.46 | 0.23 | 2.1 |

Only species contributed more than 2% biomass; carbon are shown.

**Table 3.** Uses of harvested wood and their proportional contributions (%) to overall harvesting intensity in Manga Reserve.

| Purpose | Number of sampled stumps ($Nha^{-1}$) | All Stumps (%) |
|---|---|---|
| Charcoal | 165 | 88.3 |
| Timber | 17 | 9.2 |
| Poles | 3 | 1.6 |
| Explosives | 1 | 0.1 |
| Ropes | 1 | 0.4 |
| Total | 187 | 100 |

**Table 4.** Harvesting intensity (wood and carbon removals) in Manga Reserve, Chunya District Tanzania.

| Stump age | Stems ($Nha^{-1}$) | G ($m^2ha^{-1}$) | V ($m^3ha^{-1}$) | Biomass ($tha^{-1}$) | Carbon ($tha^{-1}$) |
|---|---|---|---|---|---|
| New Stumps | 107 ± 8 | 0.98 ± 5.1 | 6.63 ± 3.0 | 5.55 ± 0.2 | 2.7 ± 0.2 |
| Old Stumps | 80 ± 6 | 0.55 ± 3.4 | 3.90 ± 2.0 | 2.85 ± 0.2 | 1.4 ± 0.1 |
| Total | 187 ± 9 | 1.53 ± 5.06 | 10.53 ± 3.1 | 8.4 ± 0.4 | 4.1± 0.90 |

**Table 5.** Major harvested species and their contribution to total carbon loss in Manga forest reserve.

| Species name | Biomass ($tha^{-1}$) | Carbon ($tha^{-1}$) | Carbon (%) |
|---|---|---|---|
| *Brachystegia spiciformis* | 4.76 | 2.38 | 70 |
| *Brachystegia boehmii* | 0.42 | 0.21 | 6.3 |
| *Pterocarpus angolensis* | 0.88 | 0.44 | 13 |
| *Other species* | 0.74 | 0.37 | 11 |

which poses pressure in nearby woodlands and forest. Estimated annual harvesting from this study exceeds reported mean annual increment (MAI) of miombo woodlands which is estimated to be 1.88-4.35 $m^3ha^{-1}year^{-1}$ (Ek, 1994; Malimbwi et al., 2005). Thus, the patterns of harvesting are definitely changing the structure and com-

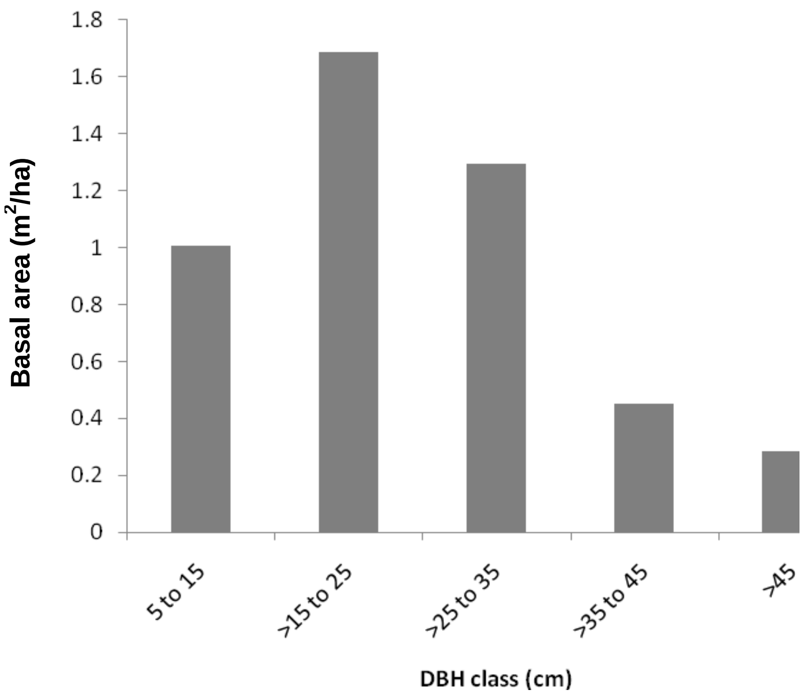


**Figure 3.** Basal area distribution by diameter classes in Manga forest reserve.

position of the vegetation substantially.

## Woodland structure

Despite the miombo of Manga showing decrease in number of stems with increase in diameter (Figure 2) class which is normally expected in well stocked natural forest, this study recorded an average of 232 ± 13 stemsha$^{-1}$ which is less as compared to reports from other study in miombo woodland. It has been reported that, stem density in miombo woodlands varies widely; however, it ranges from 380 to 1400 stems per hectare (Nduwamungu and Malimbwi, 1997; Mafupa, 2006; Mohamed, 2006). Malimbwi and Mugasha (2002) and Mohamed (2006) reported average number of stems per hector of 355 and 817, respectively in miombo woodlands of Handeni Hill forest reserve. Furthermore, this study reported mean basal area of 4.73 ± 0.5 m$^2$ ha$^{-1}$ and mean volume of 32.6 ± 2.3 m$^3$ha$^{-1}$ and their plotting against diameter class did not follow normal J shape which is expected in healthy natural forest (Figures 3 and 4). The values of total volume and basal area reported in this study are lower as compared by what has been reported by other studies in miombo which reports a range of 7 to 25 m$^2$ ha$^{-1}$ (Nduwamungu and Malimbwi, 1997; Zahabu, 2001; Mafupa, 2006; Mohamed, 2006; Maliondo et al., 2005). The lower basal area in relation to miombo ecoregion reported in this study can be explained by variation in methodologies, however wood exploitation rate reported might have considerable impacts on standing parameters. It was also noted from this study that southern miombo have high potential for carbon storage and wood material supply if utilization would be sustainable, this is indicated by standing volume of 32.6 ± 2.3 m$^3$ha$^{-1}$ despite heavy utilization for charcoal and timber which led to annual harvesting of 6.63 m$^3$ha$^{-1}$yr$^{-1}$.

## Carbon stock and emissions

Study estimate average carbon density of 10.6 ± 1.3 tCha$^{-1}$ which is relatively lower than carbon reported in similar studies by Munishi et al. (2010) and Zahabu (2008) who reported carbon density of 19.12 tCha$^{-1}$ for un degraded miombo of southern Tanzania, 21.1 and 19.89 tCha$^{-1}$ for miombo of Kitulangalo and Kimunyu Reserves in Eastern Tanzania, respectively. These differences in carbon densities might be due to varying degrees of exposure to human degradation, difference in age of the tree species and the type of miombo woodland involved (Shirima et al., 2011).

Woodland degradation emanating from human disturbances searching for their livelihoods in Manga reserve has resulted in a loss of 4.1 ± 0.9 t Cha$^{-1}$ (equivalent to 15.05±3.3 $tCO_2$e ha$^{-1}$) new harvests presenting more loss of 9.91 $tCO_2$e ha$^{-1}$ as compared to old harvesting 5.14 $tCo_2$ e ha$^{-1}$. Presence of many new stumps as compared to old stumps which were found to be uprooted by the locals in some areas for shifting cultivation, explains the estimated higher values of annual carbon loss and hence emissions. These removals are higher as compared to reports from other scholars in miombo woodlands of Tanzania. Zahabu (2008) recorded a biomass loss of 1

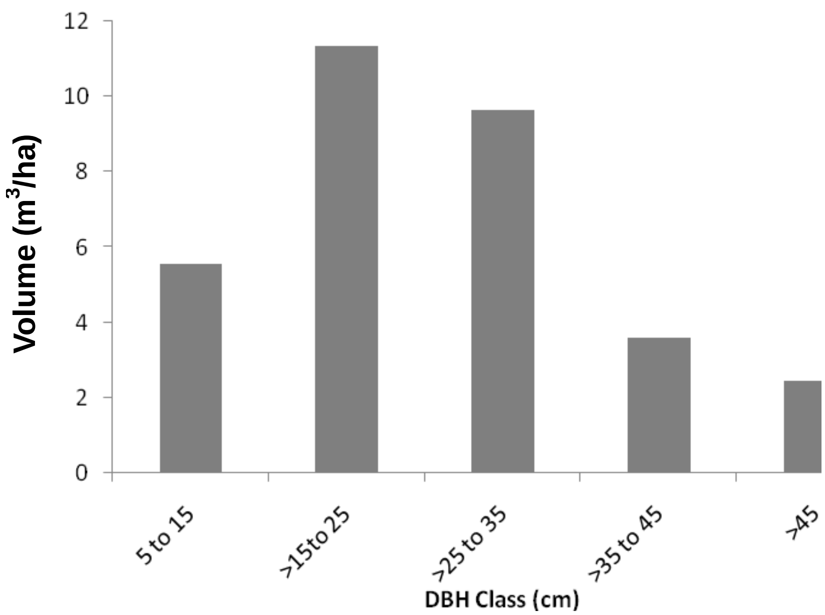


**Figure 4.** Volume distributions by diameter classes in Manga forest reserve.

and 3.5 t $ha^{-1}yr^{-1}$ equivalent to $Co_2$ emissions of 1.8 and 6.5t $ha^{-1}yr^{-1}$ for the woodland forests at Kitulangalo and the lowland and montane forests of Handei in Tanzania. Elsewhere in Miombo woodlands of Sofala province Central Mozambique, William et al. (2008) reported higher carbon take-off 0.26 $MtCha^{-1}year^{-1}$ estimated by inventory and remote sensing data. Godoy et al. (2011) estimated a carbon dioxide loss of 0.2 $MtCo_2yr^{-1}$ resulting from deforestation of Tanzania coastal forest for seven years period (2000-2007). Full potential of terrestrial ecosystems in carbon sequestration can only be realized through conservation. *B. spiciformis, P. angolensis* and *B. bohemii* (Table 5) which were found to be key species contributing to total carbon, however were also the most exploited for timber and charcoal, thus low above ground carbon.

## Conclusion

This study has reported large levels of harvesting which not only results into high rates of carbon dioxide emissions, but also they are not parallel to what is recruited which suggest that the woodlands is exploited than its producing capacity, as the annual wood removal of 6.63 ± 3.0 $m^3ha^{-1}$ exceeds the MAI of 4.35 $m^3ha^{-1}yr^{-1}$. Although, there is considerable volume in forests reserve, there is substantial utilization of key species which are potential for carbon sequestration as they constitute large part of the ecosystems, indicating that the reserve is not being effectively managed. This paper calls for appropriate management strategies to ensure sustainability of this ecosystem.

Apparently, there is tremendous capacity for the miombo ecosystem to store carbon and act as carbon sink if properly managed. Efforts to ensure proper mana-gement of the miombo ecosystem putting emphasis on important species e.g. *B. spiciformis*, *B. bohemii, P. angolensis* can contribute to creation of considerable car-bon sink as well as ensure persistent potential for the miombo woodland to store carbon as sinks rather than emissions sources thus contributing to the REDD+ pro-cess in Tanzania and global initiatives at large. Moreover, there is a need for further studies which will incorporate satellite images to estimate changes in forest canopy due to fire and agricultural farming observed in the study area.

## ACKNOWLEDGEMENT

This study was funded by CCIAM programme in Tanzania jointly implemented by Norwegian government and Tanzania government.

Thanks to Mr Mwangoka from TFCG for his taxonomic expertise and assistance with plant identification in the field. We are also thankful to Mr Luguta for field assistance in Mapogoro Chunya.

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