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Increased Biomass for Carbon Stock in Participatory Forest Managed Miombo Woodlands of Tanzania

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Abstract

Miombo (*Zambezian savanna*) woodlands are important forest vegetation in Tanzania. The forests contain biomass which is vital for climate change mitigation strategy. However the extent of increasing biomass under participatory forest management for carbon sequestration and storage is not clear. Understanding of this biomass will aid development of effective climate change mitigation strategies and promote sustainable forest management. This study involved 276 systematically determined concentric sample plots laid out in eight miombo woodland forests (four in Mbeya region and four in Iringa region). Of these plots, 145 were laid in participatory managed forests and 131 in reference scenario, called business as usual (BAU) or open access forest selected in proximity. The main finding was that most of PFM forests had significant increase in biomass ($P < 0.05$) as compared to the reference scenario. Mean biomass increased from 48.05 t/ha ± 0.03 to 37.91 t/ha ± 0.19 in PFM forests. Likewise mean biomass was 37.91 t/ha ± 0.11 to15.79 t/ha ± 0.13 for reference scenario BAU forests. This implied higher average carbon stock in participatory managed forests (21.37 t/ha) against the reference scenario (11.28 t/ha). The results provide evidence that participatory forest management approach in miombo woodlands of Tanzania have potential for climate change mitigation strategies. Despite the challenge in determining reference scenario, these findings present useful benchmark against which further study can be performed.

Keywords: Participatory forest management; Increasing forest biomass; Carbon stock; Miombo woodlands; Southern highland; Tanzania

Introduction

Miombo woodlands (*Zambezian savanna*) are important forest vegetation in the world, playing a vital role in social, economic and environmental aspect. Being an important center of plant biodiversity, miombo is a key provider of goods and services supporting the livelihoods of more than 65 million people in Africa. The woodland covers between 2.7 and 3.6 million km eastern and southern Africa [1]. Miombo woodlands cover about 90% of forested Tanzanian land [2]. From the environmental point of view miombo is determinant to energy, carbon and water balance [3,4]. Given the importance of miombo woodlands as a reservoir of above-and below-ground carbon, it represents potential for implementation of climate change mitigation strategies [5,6]. However, research on carbon dynamics in miombo woodlands is still incipient [5,7]. According to Robinson et al. [8] this needs to be evaluated more systematically [8].

Understanding of increasing biomass and carbon stocks are essential step in accounting for ecosystem goods and services particularly when considering land use options and strategies to promote carbon sequestration [9,10]. This is relevant for implementing carbon credit market mechanisms such as REDD+, which seeks to mitigate climate change through enhanced CO_2 storage in terrestrial ecosystems. REDD+ is a global policy mechanisms to reduce emission from deforestation and forest degradation as well as the role of conservation, sustainable management of forest and enhancement of forest carbon stocks [11,12]. In Tanzania REDD+ is firmly placed within the scope of participatory forest management regime [11,13]. Forest conservation policy in Tanzania thus grounds itself in the local setting rather than imposing more top-down or pure enforcement approaches to forest conservation [8,14,15]. This approach is increasingly common in low-income countries.

Participatory Forest Management (PFM) involves Community Based Forest Management (CBFM). This is one kind of PFM approach that take place on village land, on forest that are owned or managed by village council on behalf of the village assembly. This leads to the establishment of Village Land Forest Reserve (VLFR), Community Forest Reserve (CFR) or Private Forest Reserve (PFR). Furthermore, Joint Forest Management (JFM) is another form of PFM practiced in Tanzania. This is implemented to the forest reserves with high biodiversity and catchment value [16]. Under JFM, forests are jointly managed by different stakeholders, such central or local government and local communities, private sector or any other authorized body. The forest continues to be under the ownership of the government while management responsibilities and benefits are shared.

The fundamental hypothesis of PFM are found in literature (e.g. Agrawal and Gibson [17]) includes (a) greater local control over forest management results in more heather (vigorously growing) forest and woodlands due to better protection and ecologically sustainable utilization (b) greater local control and increased local community benefits associated with forest and forest management. Despite of the plausible hypothesis behind it, yet still unclear to the extent at which the forest biomass are increasing under PFM [13,18] and livelihoods objectives are being realized in Tanzania [16,19,20].

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Various authors have indicated that decentralization in forest management lead to improved forest conditions [16,19-21]. However, attention to miombo woodlands under PFM and the increasing biomass potentials for carbon storage is limited. According to Buongiorno et al. [22], forest biomass is important for assessing the productivity and sustainability of the forest. It also gives an idea of the potential amount of carbon that can be sequestered, stored or emitted in the form of carbon dioxide when forests are being cleared [10]. The above-ground biomass of a tree constitutes the major portion of the carbon pool [23,24]. Forest biomass is the most important and visible carbon pool of forest ecosystem which can also be easily affected by management [9].

While some progress has been made in reducing deforestation and forest degradation through participatory forest management in Tanzania, a large portion of miombo woodlands still not well managed [25]. This unmanaged forest is regarded as open access or business as usual forest, i.e., access is free and unregulated, possibly because rights are only nominal and unenforced. In this study the open access forest or business as usual was used as reference scenario to compare with PFM forests. Based on this background, this study examined the extent of increasing above ground biomass under PFM managed miombo woodland of southern highlands of Tanzania. This was compared with baseline or without PFM case as a reference scenario selected in proximity. The study provided more empirical evidence over the potential of PFM for furthering sustainable forest management and REDD+ initiatives.

Materials and Methods

Description of the study area

The study was carried out in Iringa and Mbeya regions, southern highlands of Tanzania. In these regions, PFM was developed and implemented since 2004 through the support of Danida-funded MEMA and or HIMA projects. The regions have been among the best practice in PFM implementation in Tanzania [26]. It was developed to suit the needs and capacities of local community. Ecologically, the study sites represent miombo woodland forests with annual rainfall of about 500-600mm, mean annual temperature 21°C. The soils in the area are nutrient poor and natural vegetation is dry miombo woodlands [27]. In this area, PFM and Non PFM forests in proximity were purposively selected for comparison (Table 1).

All studied forests under PFM had management plan and/or joint management agreements and bylaws in place, signed and in use. Actors in JFM and CBFM arrangements include the Forest and Beekeeping Division, Tanzania Forest Service, district forest officers, village executive officers, local communities and village assemblies that both have regulation and facilitation roles in forest management. In order to project extent of biomass in the PFM forests and or without PFM activity, the adjacent forests as business as usual (BAU) scenario or open access resource was used. This provided baseline information for comparison due to the lack of data on the initial condition of the forest.

Description of forest inventory techniques used in this study

The procedure for forest inventory was based on MacDicken [24], MNRT [28]; and from good practice guidance for land use, land use change and forestry [23]. Total of 276 concentric circular plots were surveyed in community based forest management and joint forest management regimes, including the counterpart BAU forests. Of these plots, 155 plots were sampled from CBFM and 121 were sampled from JFM as guided by sample size determined during reconnaissance survey. For all study forests, the first plot was located randomly at 100 m from the boundary of the forest using a Global Positioning System (GPS). Thereafter, subsequent plots were located systematically along transect lines at intervals of 200 m between plots and distance between transects varied from 250 m to 300 m to cover gradients of forest composition and structural characteristics. This also ensured the inclusion of probable deforestation and degradation centres. The direction and plot centre was located using GPS. Concentric circular plots of maximum radius of 15 m were used with the aim of increasing measurement accuracy and sampling intensity of larger trees and saving time [28]. In each sample plot (0.07 ha), plot number, slope, aspect, vegetation type and coordinates were recorded to help in characterization of the forest.

The following measurements and visual assessments were taken for individual trees in each plot: Radius 2 m: Measure and record diameter of all trees with DBH ≥ 1 cm, Radius 5 m: Measure and record diameter of all trees with DBH ≥ 5 cm, Radius 10 m: Measure and record diameter of all trees with DBH ≥ 10 cm, Radius 15 m: Measure and record diameter of all trees with DBH ≥ 20 cm. Since there were no records for harvested wood in both JFM and CBFM forest reserves and open assess forests, number of felled trees were recorded from stumps [29]. Basal diameter (BD) of tree stumps that were harvested within the 15 m radius plot was also recorded and determined as "Newly harvested (stumps harvested within the last year) and old harvested stumps (stumps harvested more than a year previously) based on the stump condition.

The distinction between new and old stumps were established by the colour and freshness of exposed wood, the size of sprouts/coppices and the presence of fire scorch on exposed wood [29]. In each case, trees and stumps measured were identified using vernacular names with the help of knowledgeable local elders (three in each site) well acquainted with ethno botany and aspect of wood utilization and management in their respective villages. These elders were selected among members for environmental committee of the village who participated in daily activities of forest management. The criteria used for identification of the harvested species were coppice growth, wood and bark characteristics and the symmetry of the stump. In addition,

Name of forests	Management regime	Area (ha)	No. of villages	Inhabitants	Inhabitants per ha forest
Mandumburu	CBFM	450	2	3,236	7.19
Ngombe	Open access	unknown	3	4,878	unknown
Shikula	CBFM	1,265	3	5,619	4.5
Senjere	Open access	unknown	2	2,873	unknown
Kitapilimwa	JFM	3,699	5	10,092	2.73
Manyamimbi	Open access	unknown	3	5,113	unknown
Chumwa range	JFM	12,298	6	13,214	1.08
Isingana	Open access	unknown	2	1,987	Unknown
Source: Field visits, 2012					

Table 1: Selected forests, its area and their management regime used in this study.

the following criteria were used to determine the reason for harvesting: species, size, and stump height, presence of fire scorch and proximity of charcoal kiln or sawing platform to the stump. Furthermore, the overall disturbance signs were also recorded for example signs of fire, kilns, grazing or fuel wood collection or clear felling for the degradation intensity assessments.

Data analysis

Data analyses involved computation of forest variables in terms of number of stems per hectare (N), basal area (G m^2/ha), volume (m^3/ha), biomass (t/ha) and carbon stock (t/ha) for each plot. It was logical to express the forest stocking by diameter size class in order to depict increasing biomass from both young and mature trees. Appropriate allometric equations for computation of both volume and biomass of each individual tree and per plot were identified through pre-tested several allometric equations. Allometric equation developed by Chamshama et al. [30] for miombo woodlands of Tanzania was selected and used. This equation includes trees greater than 1cm 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 = $0.0625dbh^{2.553}$ Where Biomass = total tree biomass (kg/ha) and dbh= tree diameter at breast height (cm) ($R^2 = 0.97$).

The estimated biomass was then converted to carbon using a biomass carbon ratio of 0.5 and for below ground biomass, root: shoot ratio value of 0.40 [31,32]. In addition, the total tree volume was calculated from the allometric equation developed by Malimbwi et al. [33]. The equation was: $V = 0.000011972dbh^{3.191672}$ Where V = tree volume (m^3) and D = tree dbh (cm) ($R^2 = 0.98$). It was also possible to compute some other forest stand variables such as: density (N) and basal area per hectare (G). These variables are very important in forest management as they provide useful information on forest stocking levels [22]. Tables and histograms derived from diameter class measurements were used to display forest structure and regeneration patterns which helped to assess the productivity and sustainability of the forest. Paired T test statistics was used to draw statistical inference of the differences between PFM and BAU in terms of biomass and carbon stock.

Results and Discussions

The state of forest resources based on management regime

The analysis of forest resource condition has revealed higher basal area and volume in JFM forests than CBFM forests (Table 2). However, an overall result from managed forest in either CBFM or JFM called PFM shows higher basal area and volume as compared to business as usual (BAU). This indicates domination of larger diameter trees in PFM forests in contrast to BAU forest. This observation was expected and correspond well with findings of other authors Lund and Treue [34], Zahabu [13]. The reason could be that JFM is being implemented in most catchments forests of high biodiversity value and CBFM in the areas where previously was open access and are now in the status of regenerating forests [34]. The number of stems varied considerably among the management regime, ranged from 1,757 to 3,527 stems ha^{-1}.

Stems density was higher in Ngombe BAU forest while basal and volume is small in comparative terms. This indicates that small diameter tree dominated the forest which is contributing little amount to basal area and volume. More interesting is that forests in all management regimes have shown to be regenerating vigorously (Figure 1). This is not only increases carbon storage potential but also important in carbon sequestration. The number of stems per hectare distribution based of diameter class shows a typical "inverse J"-shape size distribution (Figure 1). This regeneration patterns is very common in re-growing health natural forests [27]. The number of trees per unit area decreases progressively as the size of the trees increases. Although number of stems varied considerable among forests and management regimes, they are similar with the previously reported findings in different parts of Tanzania [30,35].

This finding portrays presence of recruitment of tree size from smaller diameter class to larger as expected in natural forests. The larger number of trees in smaller diameter class is an indicator for regenerating forests. In this case, the forest biomass also increases as some new trees are adding in different diameter classes and therefore improvement in biomass and carbon sequestration.

Biomass and carbon stock density in PFM and non PFM forests

Generally forest biomass and carbon stock density was found to have significant difference among practised management regime as expected

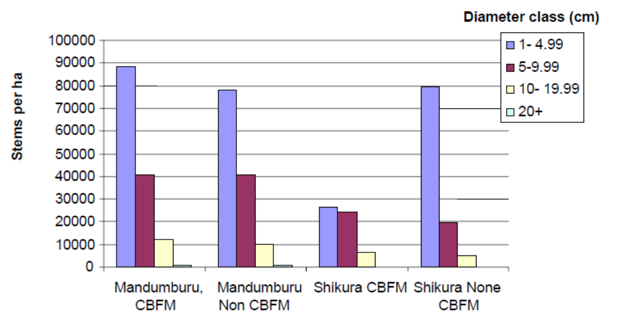

Figure 1: Tree diameter class distribution in PFM and non PFM forests.

Forest name	District	Management	N (ha^{-1})	G (m^2/ha^{-1})	V (m^3ha^{-1})
Mandumburu	Mufindi	CBFM	2664 ± 299	9.23 ± 0.49	58.63 ± 1.20
Ngombe	Mufindi	BAU	3216 ± 356	10.71 ± 0.76	51.35 ± 6.19
Shikura	Mbozi	CBFM	2931 ± 613	9.13 ± 0.82	55.80 ± 5.44
Shikura	Mbozi	BAU	1804 ± 306	7.65 ± 0.99	25.09 ± 2.29
Kitapilimwa	Iringa rural	JFM	2995 ± 391	11.13 ± 1.44	67.67 ± 9.42
Kinywanganga	Iringa rural	BAU	2764 ± 497	7.65 ± 0.99	32.45 ± 4.13
Chumwarange	Mbozi	JFM	1757 ± 370	9.83 ± 1.92	73.27 ± 11.31
Namlonga	Mbozi	BAU	3527 ± 456	7.74 ± 0.67	15.79 ± 2.20

Note: N is the number of stems ha^{-1}, G is the basal area (m^2ha^{-1}) and V is the volume (m^3ha^{-1}), number after ± are 95% confidence limits (products of standard errors of the mean and t-value at 95% confidence level).

Table 2: Status of forest resource based on management practiced in the study area.

(Table 3). This could be explained by management interventions and the degree of effectiveness to limit disturbances from human activities. PFM practice increased miombo woodlands biomass accumulation with positive implication to carbon sequestration and storage. The highest carbon stock observed at Chumwarange JFM forest (24.03 t/ha) ± 0.12 followed by Mandumburu CBFM forest (21.59 t/ha) ± 0.41.

The different in biomass as well as carbon stock in Mandumburu CBFM and Ngombe without PFM is not significant different ($P > 0.05$). This is not expected however, it could be influenced by selection of baseline scenario or effectiveness in implementation of PFM regulations. What constitutes appropriate BAU forest to compare with PFM forests was determined in consultation with local communities and their forest records.

Threat to biomass and carbon stock accumulation in miombo woodlands

Miombo woodlands are affected by both deforestation through the clearance for agriculture and fire and degradation through the utilization of wood products [14,25]. Agriculture provides both income and food for local people and utilization is vital to local livelihoods. Through the use of miombo woodlands resources local communities can prevent households from failing into poverty [18].The woodland provides alternative food sources, medicine, fuel wood and income. This study observed different signs for deforestation and forest degradation activities persisting despite PFM practices in miombo woodlands of Tanzania.

Stumps and other deforestation and forest degradation signs were observed and analyzed with respect to PFM and non PFM practices. The results showed more biomass removal through illegal activities in non PFM forests as compared to PFM forests (Tables 4 and 5). This observation indicates that biomass threatening activities dominated in non PFM forest and were reduced in PFM forests. This observation is consistent with the findings from other authors (e.g. Blomely et al. [15]; Zahabu [13]). This can be attributed to poor management and or level of forest resource dependence pressure from local livelihoods. It is therefore important to be more focused before the implementation of REDD+ initiatives. This also calls for more effort to enforce PFM rules and regulation to control illegal activities in reserved forests.

Likewise, the study documented different signs of activities threatening miombo woodland biomass accumulation with different magnitude between PFM and BAU forest (Table 5).

Among miombo woodlands biomass threatening activities, firewood collection and browsing from livestock were revealed to have high score. This implies that the extent of illegal activities was more pronounced in non PFM forests. Moreover, checking the time period from which these illegal activities occurred, frequency of old stumps before PFM implementation was high compared to after PFM practises (Figure 2). This provide evidence that PFM practices have reduced illegal activities in the forest, however more effort is need to alleviate all forest threatening activities for REDD+ initiative.

However, deforestation and forest degradation activities exist in both PFM and non PFM forest with different magnitude. Several reasons can plausibly be used to explain this finding, which also challenged the setting up of reference scenario. First, in the study sites the by-laws which are meant to guide the management of forests under PFM are also applied in non-PFM forests. Consequently the 'leakage' is minimised, rendering the forest improvements in open forest as well. This argument is consistent with Vyamana [36] who found that particularly in the CBFM the problems of leakage were less significant

Forest name	District	Management	Biomass (t/ ha^{-})	Carbon (t/ha^{-1})	P-value
Mandumburu	Mufindi	PFM	43.18 ± 0.87	21.59 ± 0.41	0.347
Ngombe	Mufindi	Without PFM	37.91 ± 0.11	18.96 ± 0.05	
Shikura	Mbozi	PFM	37.91 ± 0.19	18.65 ± 0.09	0.004
Shikura	Mbozi	Without PFM	17.80 ± 0.09	9.20 ± 0.04	
Kitapilimwa	Iringa rural	PFM	42.43 ± 0.19	21.22 ± 0.09	0.020
Kinywanganga	Iringa rural	Without PFM	20.66 ± 0.29	10.33 ± 0.08	
Chumwarange	Mbozi	PFM	48.05 ± 0.03	24.03 ± 0.12	0.000
Namlonga	Mbozi	Without PFM	15.79 ± 0.13	6.64 ± 0.04	
Note: Number after ± are 95% confidence limits (products of standard errors of the mean and t-value at 95% confidence level) and P-value is the 0.05 significance level.					

Table 3: Comparative results of biomass and carbon stock in PFM and without PFM forests.

Management regime	Stumps density (N/ha)	Basal area (m^2/ha)	Volume (m^3/ha)	Biomass (t/ha)
JFM (n=60)	891 ± 44	0.531 ± 0.025	3.276 ± 0.155	2.569 ± 0.144
BAU (n=60)	1230 ± 29	0.675 ± 0.026	4.168 ± 0.160	3.196 ± 0.146
CBFM (n=83)	919 ± 15	0.285 ± 0.012	1.76 ± 0.074	1.103 ± 0.055
BAU (n=70)	2220 ± 32	0.394 ± 0.010	2.43 ± 0.059	1.660 ± 0.045
Note: Numbers after ± are standard deviation of the means and t-value at 95% confidence level.				

Table 4: Harvested biomass as measured from stumps in PFM and Non PFM forests.

Deforestation and forest degradation activities observed	Frequency of occurrence in a sample plots				
	JFM (n=60)	BAU (n=60)	CBFM (n=83)	BAU (n=70)	Overall
Fire signs	4	14	3	11	32
Browsing	2	27	8	32	69
Charcoal burning	3	15	6	16	40
Firewood collection	12	28	9	27	76
Encroachments	2	12	1	6	21

Table 5: Observed signs of degradation in JFM and CBFM as compared to BAU.

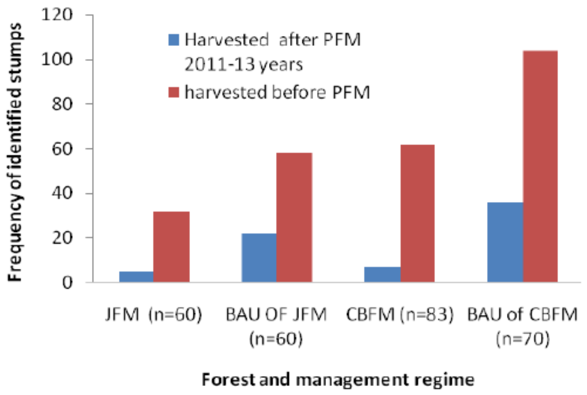

Figure 2: Observed number of stumps in JFM and CBFM forests compared to open access (BAU).

because by-laws developed for a given area of forest were generally applied in the whole village landscape.

The second possible explanation for the revealed trend is the proximity between the studied PFM forests and their counterpart non-PFM forests. During sampling processing, the non-PFM forests were those ones almost sharing the same boundaries with respective PFM forests. It is therefore reasonably to argue that the best management practices in PFM are by default extended to the neighbouring non-PFM forests (spillover effect). PFM practice could have positively changed villager's attitudes towards utilisation of non-PFM forests as well.

The increased biomass and implication for climate change mitigation

The biomass in miombo woodlands under PFM revealed to be increasing and that the forest regenerates more vigorously in PFM compared to open access. The results provide hope for participatory forest management to reverse the deforestation and forest degradation trends in miombo woodlands of Tanzania. The increased biomass therefore represents a great opportunity for REDD+ initiatives and benefits from emerging carbon markets. This increase in biomass has been possible due to the local communities' efforts to protect miombo woodlands from illegal activities such as burning and grazing. The practice of PFM have permitted miombo woodlands biomass to increase and therefore increased carbon storage capacity.

Local communities through PFM have been able to bring about these improvements by the way they interact with the forest, albeit with the guidance of the district forest officers and NGOs. PFM have built solidarity and social control within the village and ensure that forest management plans and bylaws, once made, are largely adhered to. Although the PFM rules and regulations were made for PFM forests, it could have impacted across the whole village forest landscape and therefore protect also open access forest. This practice has led to small difference in biomass observed in some forest like Mandumburu forests in Mufindi district. Despite of this, the overall results have shown significant differences in increased forest biomass under PFM as compare to non PFM management. This increase would therefore be advantageous for REDD+ policy strategy of climate change mitigation in Tanzania.

Conclusions and Recommendations

Given the observed biomass increase in PFM forest as compared to business as usual or open access management, PFM presents potential for implementation of REDD+ policies. This will promote sustainable forest management and socio-economic development in Tanzania. There is also considerable recruitment level and reduced illegal activities in PFM forests. This observation presents good potential for carbon sequestration and storage under climate change mitigation strategies. Even though these results may be challenged from baseline or initial condition of the forests, however, the use of large number of sample plots covering wide range of miombo woodlands and socio-economic setting increased the reliability of the findings. These findings represent useful benchmark against which further and more accurate study can be performed before a decision is made on engaging in REDD+ initiatives. Other factors which were not controlled might have been contributed to the observed results. Factors like ecological condition, soil productivity or site class, the condition of the forest before PFM establishment and socio-economic conditions of the adjacent communities.

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