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Estimation of Biomass and Carbon stock for Miombo Woodland in Dzalanyama Forest reserve, Malawi

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Abstract

Successful design and implementation strategies designed to reduce emissions through the forestry sector requires an understanding of carbon dynamics. A study was conducted to estimate the living biomass and carbon stock for miombo woodland in Dzalanyama forest reserve with the purpose of providing data for sustainable forest management and baseline data for carbon monitoring, and also to predict the existence of miombo woodland in Dzalanyama forest reserve if the current trend of charcoal and fuelwood production is unchecked. The results shows that there is substantial amount of living biomass (61.6 tonnes ha⁻) and carbon stock (30.8 tonnes ha⁻) for miombo woodland in the reserve. There were significant (P<.001) differences between dbh classes on number of stems per hectare with the dbh class of 5-14.9cm having the highest number of stems per hectare. Site observation showed that there are more regenerants. This imply that if trees and the regenerants are sustainably managed then the amount of living biomass and carbon stock would increase in the subsequent years as the trees and the regenerants grow. The uncertainty for the estimated living biomass and carbon stock were low (<7%). The results also shows that if the current trend of illegal harvesting of trees for charcoal and fuelwood production is unchecked, the miombo woodland forest in the reserve will be completely exhausted in the next 10 years. Therefore, it can be concluded that there is potential for REDD+ activities to be carried out in Malawi with Dzalanyama forest reserve as one of the site. However, a decisive action is required in order to address deforestation and forest degradation of the reserve.

Keywords: Forest management; REDD+; uncertainty; regenerants.

Introduction

The rising of atmospheric CO_2 concentrations is a major concern in the modern society[1,2]. The increase in greenhouse gases is projected to lead 1 – 3.5^{0}C in global mean surface temperature by the year 2100[3]. Forest play an important role in the global carbon cycle because they store large quantities of carbon in vegetation and soil, and are sources of atmospheric carbon when they are disturbed by natural causes or human[4,5]. It is estimated that forests contains 638 GtC in their ecosystem as a whole, with 238 GtC in biomass alone[6]. The quantity of biomass in a forest determines the potential amount of carbon that can be added to the atmosphere or sequestered on the land when forests are managed for meeting emissions targets[5].

Successful design and implementation strategies designed to reduce emissions through the forestry sector requires an understanding of carbon dynamics i.e. the rate of carbon loss or accumulation[7,8]. Accurate data on carbon stocks and carbon stock change over time are of particular interest for countries like Malawi in the light of possible future financial mechanisms that are discussed in relation to reducing emissions from deforestation and forest degradation, or managing and enhancing carbon stocks (REDD+)[9]. REDD+ is a proposed performance-based mechanism, in which developed countries compensate developing countries for forest emissions reductions through a variety of anticipated financial mechanisms, working at different scales[9,10]. Through, REDD+ mechanism, five options are considered: i. information on the size of carbon stocks, ii. reduced deforestation and carbon stock conservation, iii. additional data on carbon stock changes over time, iv. reduced forest degradation, and v. sustainable forest management and carbon stock enhancement[11]. Therefore, REDD+ is one of the significant essential mechanism to address the issues of climate change in developing countries,and this requires accurate, standard and reliable information of forest carbon stock[12,13]. Malawi is in the initial stages of REDD+. However, very few studies have attempted to estimate biomass and carbon stock on Malawi's forest and in particular Dzalanyama forest reserve, even though substantial rates of deforestation were reported. Munthali[14] estimated an annual deforestation rate of 1.7% corresponding to a total area of 22000 ha forest lost in Dzalanyama forest reserve between 1990 and 2010.Using Multi-agent simulation (MAS), Munthali[14] predicted an annual deforestation rate of 3.1% corresponding to 26700 ha forest to be lost in Dzalanyama forest reserve between 2010 and 2030. This means that by the year 2030, only 17000 ha from an initial designated boundary of 93500 ha will be left as forest cover for Dzalanyama forest reserve. Onaka[15] also reported that about 0.4Mt of living wood biomass per annum is beingillegally harvested from miombo woodland in Dzalanyama forest reserve for charcoal and fuelwood production. In view of all thesefactors a study was conducted to estimate the living biomass and carbon stock for miombo woodland in Dzalanyama forest reserve with the purpose of providing data for sustainable forest management and baseline data for carbon monitoring, and also to predict the existence of miombo woodland in Dzalanyama forest reserve if the current trend of charcoal and fuelwood production is unchecked.

Material and Methods

Study site: The study was conducted in November 2013 in Malawi located in Southern Africa in the tropical savannah region at Dzalanyama forest reserve. Dzalanyama forest reserve is located between latitudes14°11'S and 14°37'S and longitudes 33°21'Eand 33°55'E (figure-1) and has a topography of 1100 m to 1659 mabove the sea level. It receives about 800 mm to 1200 mm rainfall per annum, with a mean annual temperature ranging from 14°C to 28°C. Sitting on a range of hills bearing the same name, Dzalanyama forest reserve covers approximately 984 km^2 of land. The forest reserve is categorized into four classes with respect to forest type and state: miombo woodland (818 km^2), Pineplantation (32 km^2), Eucalyptus plantation (38 km^2), and wetland (96 km^2). It is situated about 45 km southwest of the Lilongwe city centre.

Sampling intensity and location of sampling points on a map: The required number of sample plots was determined using the following formula as outlined by Hirata Y.et.al[16]:

$$n \geq \left(\frac{t.s}{e}\right)^2$$

where *n* is the required number of sample plots, *t* is the statistic value necessary for 5% significance level of the t-distribution with (*n* – 1) degrees of freedom, *s* is the standard deviation delivered from the previous inventory data or pilot survey, and *e* is the allowable error rate (%). A recommended allowable error rate ranges from 1% to 5%[12]. In this study a 5% error rate was used. *s* was determined as 19.93 from Forest Resource Mapping Project conducted by Asia Air Survey Ltd in 2010 and *t* = 1.96. Hence, the required number of sample plots for the miombo woodland was 61. The grid interval was determined using the formula:

$$GI = \sqrt{(A/n)}$$

Where: GI is the grid interval, A is the total area of the forest stratum, *n* is the required number of sample plots. Therefore, grid interval was estimated as 4 km.

The sampling points were located on the topographic map using ArcGIS software. The first point was randomly selected, then subsequent points were placed at the intersection of the grids. The coordinates of the intersections were recorded as the centre of the plots and were uploaded in GPS receivers for location of the plots in the field.

Establishment of sampling plots and data collection: Three concentric circular plots of radius, 5.64m (small), 11.28m (medium) and 17.84m (large) were established at each sampling point (figure-2). The following measurements were taken for each tree in a plot and were recorded: Diameter at breast height (dbh) (1.3 cm above ground level) using a caliper; height using a vertex; distance and bearing from the centre using vertex and hand held compass respectively. However, trees were measured using the following standard: small plot (5cm ≤ dbh ≥ 14.9 cm); medium plot (15cm ≤ dbh ≥ 29.9 cm); and large plot (dbh ≥ 30cm). The name for each tree measured was also identified and recorded.

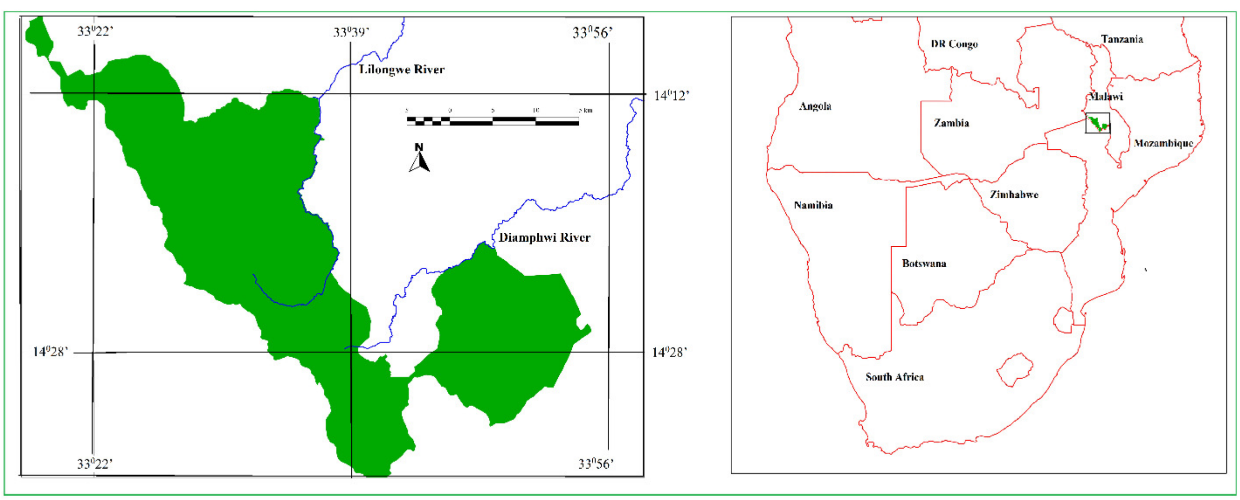

Figure-1
Location of Dzalanyama Forest Reserve in Southern Africa

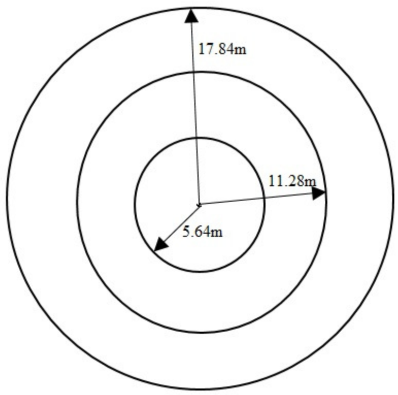

Figure-2
Plot design, size and shape

Statistical analysis: Data obtained was subjected to Kolmogorov-Smirnov D and normal probability plot tests using Statistical Analysis of Systems software version 9.1.3[17]. This was done in order to check the normality of the data. After that the data was subjected to descriptive analysis and analysis of variance (ANOVA). The characteristics of the data set are presented in table-1. ANOVA was performed in order to determine the significant differences on the number of stems per hectare between different dbh classes and differences between means were separated using Fischer's least significant difference (LSD) at the 0.05 level.

Table-1
Characteristics of the data set

Parameter	Mean	Minimum	Maximum	Standard deviation
Height (m)				
Small plot	5.9	2.5	19.0	2.7
Medium plot	10.9	6.0	25.9	3.5
Large plot	21.1	17.0	34.5	3.0
Dbh (cm)				
Small plot	8.9	5.0	14.9	2.9
Medium plot	20.9	15.0	29.8	3.9
Large plot	37.7	30.0	69.2	6.7
Density (stems ha^{-})				
Small plot	241	0	1417	99
Medium plot	100	0	450	21
Large plot	20	0	150	8

Biomass estimation: Above ground biomass (AGB) of a tree was estimated using the following equation developed by Chave J.et.al[18]:

$$AGB = \rho \times esp\{-0.667 + 1.784 \times \ln(dbh) + 0.207 \times [\ln(dbh)]^2 - 0.0281 \times [\ln(dbh)]^3\}$$

Where: AGB is above ground biomass (kg dry matter per tree); ρ is the wood density (oven-dry. tonne per moist m^3); dbh is diameter at breast height (1.3 m above the ground level) (cm); and ln is the natural logarithm. The wood density values were obtained from IPCC-GPG and academic papers. In cases where wood density values was not available, a default value of 0.60 (oven-dry. tonne per moist m^3) was used.

Below ground biomass (BGB) was calculated using the following formula developed by Cairns M.A.et.al.[19]:

$$BGB = \exp\{-1.0587 + 0.8836 \times \ln(AGB)\}$$

Where: BGB is the below ground biomass (dry matter tonne per ha).

Total living biomass of a tree (TLB) was calculated as: TLB= AGB + BGB. Subsequently, the acquired amount of TLB in kg and plot size were converted into TLB in dry matter tonne to unify unit of weight and area. The total amount of TLB per hectare in each circular plot was calculated using an expansion factor, which is the ratio of plot area to one hectare (1ha / plot size).

Carbon and uncertainty estimation: Carbon stock (C) was calculated using the following formula as outlined by AAS [20]: C = TLB x CF*;* where: CF is the carbon factor and varies from 0.45 to 0.50[16]. In this study a default value of 0.50 was used.

Monte Carlo procedure (well explained by Sierra C.A.et.al.[21]) was used to estimate uncertainty of AGB, BGB, TLB, above ground carbon stock, below ground carbon stock, and total carbon stock at 95% confidence interval.

The total living AGB estimated and the 0.4Mtlivingwood biomass, reported by15Onaka K.[15], which is illegally harvested per annum for charcoal and fuel wood production were used to predict the existence of the miombo woodland for Dzalanyama forest reserve if the current trend of illegal harvesting for charcoal and fuelwood production is unchecked.

Results and Discussion

Biomass and carbon estimation: Estimated living biomass and carbon stockfor miombo woodland in Dzalanyama forest reserve are presented in table-2. This estimates includes above total living biomass, above ground carbon stock, below ground living biomass in roots, and below ground carbon stock in roots. The results indicate that there is substantial amount of living biomass and carbon stock for miombo woodland in Dzalanyama forest reserve. The average carbon stock in above ground living biomass represented 82% of the total carbon stock. The total living biomass and total carbon stock estimated in this study are slightly lower than those reported by AAS [20]. AAS[20] reported a total living biomass and total carbon stock for miombo woodland in Dzalanyama forest reserve of 66.14 t/ha and 33.07 t/ha respectively. The difference between these values and the present study could be due to number of concentric sample plots used in the study. In the present study three concentric sample plots (small, medium and large) were used at each sampling point, while for AAS only two concentric sample plots (small and large) were used. This could somehow overestimated the values. The other possible reason could be due to high illegal harvesting of trees for charcoal and fuel wood production[14,15]. This could mean that large amount of trees have been harvested since the last inventory took place, hence low values in the present study.

There were significant (*P*<.001) differences between dbh class on number of stems per hectare (figure-3). The dbh class of 5-14.9 cm had the highest number of stems per hectare followed by dbh class of 15-29.9 cm. The dbh class of ≥30 cm had the lowest number of stems per hectare. Site observation (figure-4) showed that there are more regenerants. This imply that if trees and the regenerants are sustainably managed then the amount of living biomass and carbon stock would increase in the subsequent years as the trees and regenerants grow. The present results are consistent with those reported by AAS[20]. Therefore, it can recommended that there is potential for REDD+ activities to be carried out in Malawi with Dzalanyama forest reserve as one of the site.

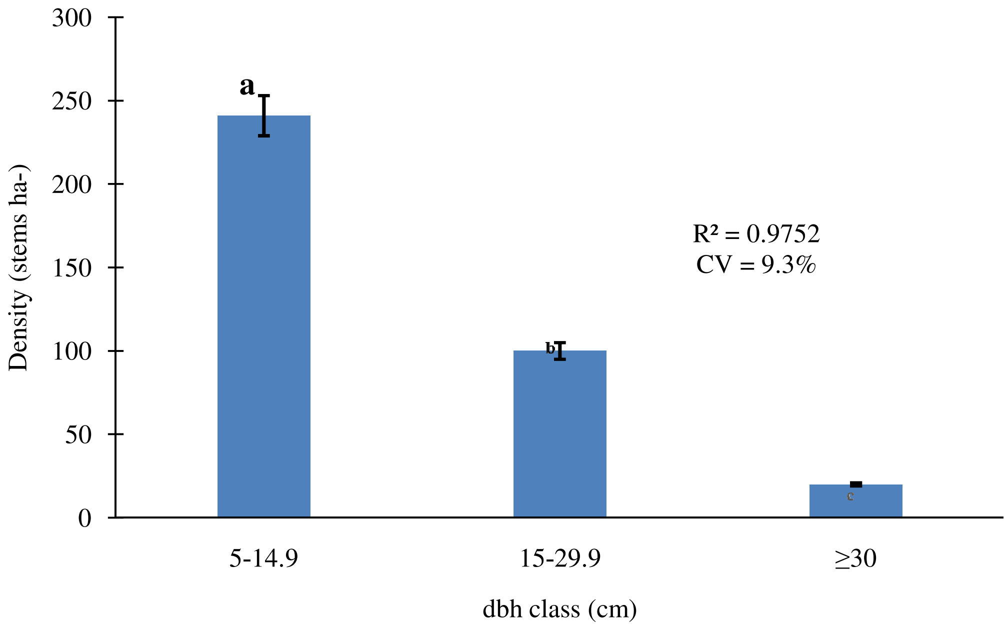

Figure-3
Distribution of number of stems per hectare within different dbh class, Note: [a,b,c]bars with different letters significantly differ (*P*<.001)

Figure-4
Photograph of regenerants of miombo woodland in Dzalanyama forest reserve taken during the inventory in November 2013

Uncertainty analysis: The estimates for uncertainty for living biomass and carbon stock are given in table-2. Biomass and carbon stock estimations are always linked with uncertainties and it is important to consider and minimize them as much as possible[22]. One of the possible sources of errors is the uncertainty of field measurements of individual trees (diameter and height) and tree architecture[23]. To minimize this, a large amount of trees totaling to 2771 were measured in this study. This large amount of trees leads to measurement errors which are normally distributed and have minimal effect on the final biomass determination[24].

Sampling size can create serious bias in biomass estimation and its carbon content[25]. Numerous authors[24 – 26] recommend that a total sampling size of roughly 5 ha or 20 plots of 0.25ha can allow estimation of the AGB with an error of ±10% within 95% confidence interval. The present study considered 61 plots of 0.12 ha each, adding to 7.32ha. The plots were uniformly distributed along the forest reserve. This were large enough to minimize the sampling size error, hence low uncertainties were estimated for this study (table-2). However, a default allometric equation that included wood density and dbhonly was used in this study. This in one way or another could overestimate or underestimate the biomass values and its carbon content[20]. Therefore, it is recommended to develop site specific allometry that would use three parameters (wood density, dbh and height). It has been reported that site specific allometric equations that include the three parameters (wood density, dbh and height) tends to have low (<5%) uncertainty[27]. The use of site specific allometry could also help Malawi to achieve Tier 3 level of accuracy for REDD+ framework.

Existence of miombo woodland in Dzalanyama forest reserve: The estimate of living AGBwas 4.2Mt (table-2) and Onaka[15] reported that 0.4Mt of living wood biomass is being illegally harvested for charcoal and fuel wood productions in Dzalanyama forest reserve annually. Therefore, this means that the amount of annual lossis equivalent to almost 10% of the current living above ground biomass. This implies that the miombo woodland forest in Dzalanyama forest reserve will be completely exhausted in the next 10 years if nothing is done to reverse the situation. This is a worrisome situation considering that Dzalanyama is one of the most valuable forest in terms of sustainability of Malawi when it comes to water supply, food security and economic growth[14]. The reserve is the source for Lilongwe and Diamphwi rivers that supplies water to the residents of the capital city, Lilongwe[15]. The catchment also forms some part of the largest agricultural production areas for maize production, the staple crop of Malawi. The annual yield of maize production from the catchment area accounts for approximately 30% of the national yield[14]. Therefore, it is recommended that a decisive action is required in order to address deforestation and forest degradation of the reserve.

Table-2
Biomass, carbon stock and uncertainty for miombo woodland in Dzalanyama forest reserve with standard errors in parenthesis

Parameter	Density (t/ha)	Total (Mt)	Uncertainty (%)
Above ground biomass (AGB)	50.8 (1.7)	4.2	6.5
Below ground biomass (BGB)	10.8 (0.2)	0.8	3.8
Total living biomass (TLB)	61.6 (1.6)	5.0	5.1
Above ground carbon stock	25.4 (0.8)	2.1	6.5
Below ground carbon stock	5.4 (0.1)	0.4	3.8
Total carbon stock	30.8 (0.8)	2.5	5.1

Conclusion

The recent study has shown that there is substantial amount of living biomass and carbon stock for miombo woodland in Dzalanyama forest reserve. There were significant differences between dbh classes on number of stems per hectare with the dbh class of 5-14.9 cm having the highest number of stems per hectare. Site observation showed that there are more regenerants. This imply that if trees and the regenerants are sustainably managed then the amount of living biomass and carbon stock would increase in the subsequent years as the trees and the regenerants grow. The uncertainty for the estimated living biomass and carbon stock were low. Hence, it can recommended that there is potential for REDD+ activities to be carried out in Malawi with Dzalanyama forest reserve as one of the site. However, if the current trend of illegal harvesting of trees for charcoal and fuelwood production is unchecked, the miombo woodland forest in Dzalanyama forest reserve will be completely exhausted in the next 10 years. Therefore, it is recommended that a decisive action is required in order to address deforestation and forest degradation of the reserve.

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