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Biomass and Carbon Stock Estimation for Miombo Woodland in Selected Part of Chongoni Forest Reserve, Dedza, Malawi

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Abstract: *Understanding the capacity of forest ecosystems to store carbon is fundamental in quantifying the contribution of trees to climate mitigation because they indicate the amount of carbon that can be offset. This study was conducted to estimate the living biomass and carbon stock for selected part of miombo woodland in Chongoni forest reserve with the purpose of providing data for sustainable forest management and baseline data for carbon monitoring. The results shows that there is significant amount of living biomass (1690±32 tonnes ha^{-}) and carbon stock (845±16 tonnes ha^{-}) for miombo woodland in the forest reserve. There were significant ($P<0.001$) differences among dbh classes on number of stems per hectare with the small dbh class (5-14.9cm) having the highest (261±3) number of stems per hectare. However, there were no significant ($P>0.05$) differences between medium dbh class (15–29.9 cm) and the large dbh class (≥30cm) on number of stems per hectare, even though the large dbh class had slightly higher (171±5) number of stems per hectare than the medium dbh class (161±5). The uncertainty for the estimated living biomass and carbon stock were low (<4%) at 95% confidence level. Further estimation of biomass and carbon stock for the remaining part of miombo woodland in Chongoni forest reserve is required, which could lead to recommendation for REDD+ activities to be carried out in Malawi with Chongoni forest reserve as one of the site.*

Keywords: *Climate mitigation, Carbon monitoring, Forest management, Uncertainty, REDD+.*

1. Introduction

Forests play an essential role in reducing an atmospheric carbon since they dominate the dynamics of the terrestrial carbon cycle [1]. Forests contains about 50% of the carbons stored in the vegetation and about 50% of the carbon stored in the soil [2]. Hence, there is growing interest in understanding carbon stocks in tropical forests [3]. Understanding the capacity of forest ecosystems to store carbon is fundamental in quantifying the contribution of trees to climate mitigation because they indicate the amount of carbon that can be offset [4].

Several studies have suggested that forest ecosystems can be a significant sink for carbon fixation [5 – 9]. In addition, the Kyoto Protocol also recommended afforestation and reforestation as the promising mitigation strategies because trees are able to absorb a considerable amount of carbon dioxide (CO_2) through photosynthesis, while wood production is recognized as a form of carbon storage [10].

Biomass is defined as the organic matter fixed by trees and the source of all other productivity in the forest [1]. Biomass is of great importance because it can be used to assess changes in the forest structure, quantify increment in forest yield, growth or productivity, and to determine energy fixation in the forest [1, 11, 12]. Despite all these, very few studies have been attempted to estimate biomass and carbon stock in Malawi's miombo woodland forest in particular Chongoni Forest Reserve, due to the focus on fast growing exotic plantations which have been prioritized by government. The miombo woodland forest is well described by [3, 13]. Therefore, the present study was undertaken to estimate the living biomass and carbon stock for miombo woodland in Chongoni Forest Reserve with the aim of providing data for sustainable forest management and baseline data for carbon monitoring.

2. MATERIALS AND METHODS

2.1 Study Site

The study was conducted in July 2014 in Malawi located in Southern Africa in the tropical savanna region at Chongoni Forest Reserve in Dedza. Chongoni is located between latitudes 14^{0}10'S and 14^{0}21'S and longitudes 34^{0}09'E and 34^{0}17'E (Figure 1). It receives 1200 mm to 1800 mm rainfall per annum, with annual temperature ranging from 7 ^{0}C to 25 ^{0}C. The altitude of the reserve varies from 1570 m to 1690 m above the sea level. It is situated about 85 km southeast of Lilongwe, the capital [14]. Chongoni Forest Reserve cover approximately 12600 ha of land. The forest reserve is divided into two units for management purposes. Unit 1 covers approximately 11200 ha is managed by Dedza District Forestry Office while Unit 2 which covers about 1400 ha is management by Malawi College of Forestry and Wildlife. Unit 2 is further categorized into two with respect to forest type: Miombo woodland (300 ha) and Pine plantation (1100 ha). So the study was conducted in miombo woodland in Unit 2.

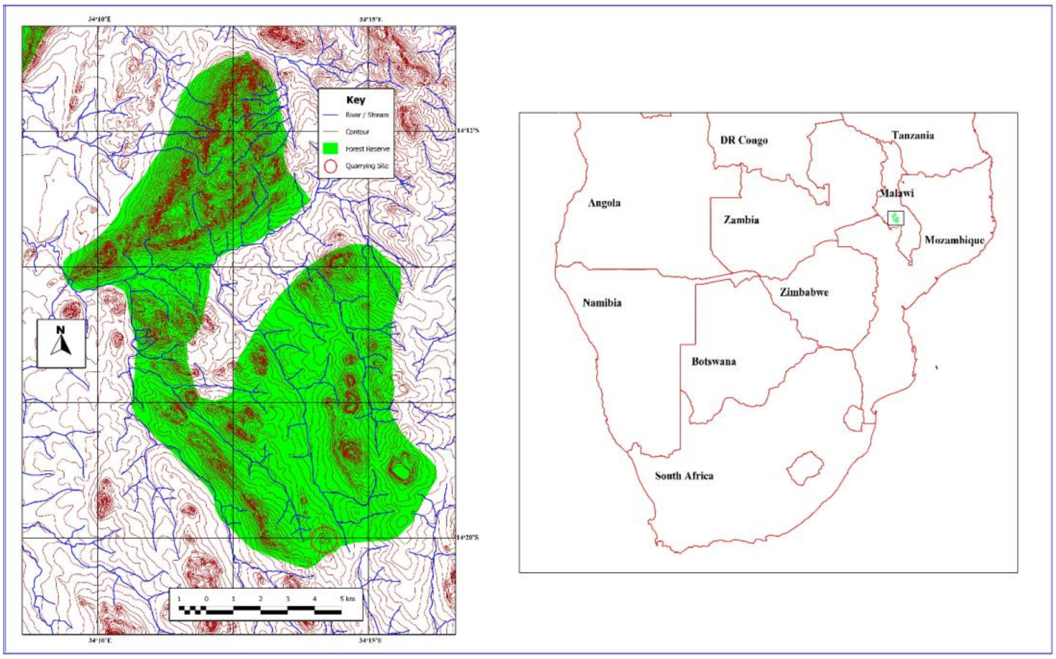

Figure1. *Location of Chongoni Forest Reserve in Southern Africa*

2.2 Sample Plots and Data Collection

The required number of sample plots and grid interval was determined using the procedure outlined by [15]. A total of forty-five sample plots at an interval of 250 m were used for the inventory. Sample plots of radius 20 m were established at each sampling point and the diameter at breast height (dbh) (1.3m above ground level) for each tree (dbh $\geq$ 5 cm) in the plot were measured and recorded. The name of each tree measured was identified and recorded.

2.3 Statistical Analysis

Data obtained were tested for normality and homogeneity with Kolmogorov-Smirnov D and normal probability plot tests using Statistical Analysis of Systems software version 9.1.3 [16]. After the two criteria were met, the data was subjected to descriptive analysis and analysis of variance (ANOVA). 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.

2.4 Biomass, Carbon and Uncertainty Estimation

Above ground biomass (AGB) of a tree was estimated using the equation:

$$\text{AGB} = SV \times \rho \times BEF$$

Where: SV is stem volume (m^3), ρ is wood density (ton per m^3), while BEF is Biomass Expansion Factor. 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 (ton per m^3) was used. Furthermore, a default value of 3.4 for BEF was used. Stem volume was calculated using stem volume equations (Table 1) developed by [17] specific for Chongoni Forest Reserve.

Table1. *Stem volume equations for dominant species and important species groups for Chongoni Forest reserve*

Species / Species group	Equation
Brachystegia floribunda	$Log_{10} V = -4.22 + 2.77 log_{10} dbh$
Brachystegia boehmii	$Log_{10} V = -3.85 + 2.49 log_{10} dbh$
Brachystegia spiciformis	$Log_{10} V = -4.30 + 2.85 log_{10} dbh$
Faurea saligna and *Faurea speciosa*	$(V)^{0.5} = 0.081 + 0.0268 dbh$
Uapaca kirkiana	$Log_{10} V = -4.19 + 2.76 log_{10} dbh$
For canopy species	$Log_{10} V = -4.22 + 2.76 log_{10} dbh$
For under-storey species	$Log_{10} V = -3.87 + 2.43 log_{10} dbh$

Note: *V = Volume, dbh = diameter at breast height (1.3m above the ground level),* Log_{10} *=Logarithm to the base 10.*

Below ground biomass (BGB) was estimated using the equation:

$$BGB = AGB \times R$$

Where: R is the root shoot ratio and varies with tree species, tree ages, and growth conditions. In this study a default value of 0.25 was used. Total living biomass (TLB), carbon stock and uncertainty were estimated using the procedure outlined by [15].

3. Results and Discussion

3.1 Distribution of Number of Trees Per Hectare Within Dbh Classes

The results on distribution of number of stems per hectare within dbh classes are presented in Figure2. The results indicates that there were significant (P<0.001) differences among dbh classes on number stems of stems per hectare. The small diameter class (5–14.9 cm) had the highest number of number per hectare. This is consistent with the results reported by [15] for Dzalanyama forest reserve. However, there were no significant (P>0.05) differences between medium dbh class (15–29.9 cm) and the large dbh class (≥30cm) on number of stems per hectare, even though the large dbh class had slightly higher number of stems per hectare than the medium dbh class. This is an indication that there is little disturbance on the miombo woodland. Site observation showed that more illegal activities are carried out in the nearby fast growing pine plantation than in miombo woodland, since the surrounding communities rely on timber as one of their source of income.

Figure 2 further shows that the distribution of number of stems per hectare for different dbh class is not normally distributed. It is skewed to the left. According to Vieira and Scariot [18], a forest which is not normally distributed in terms of number of stems per hectare for different dbh classes, that forest is considered as not sustainably managed. Hence, there is a need to promote a silvicultural system that would enable the forest to be sustainably managed and coppice with standard has been recommended as one of the future management options in management of miombo woodlands in Malawi [13].

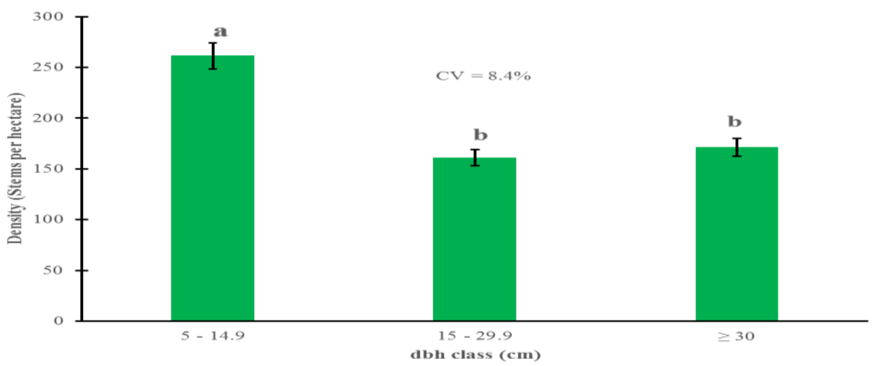

Figure2. *Distribution of number of stems per hectare within dbh class, Note:* ^{a,b}*bars with different letters significantly differ (P<0.001)*

3.2 Biomass and Carbon Estimation

Summary of the results for the estimated total living biomass, above ground biomass, below ground biomass, total carbon stock, above ground carbon stock and below ground carbon stock are given in Table 2. The results shows that there is a significant amount of living biomass and carbon stock for miombo woodland in Chongoni forest reserve. The estimated total living biomass per hectare was twenty-seven (27) times more than the one estimated in Dzalanyama forest reserve [15]. The huge different between the values for the present study and that of Dzalanyama forest reserve could be the intensity of illegal activities. There is a massive illegal cutting of trees in Dzalanyama forest reserve for fuel wood and charcoal production than in Chongoni forest reserve. It was reported that 0.4Mt of living wood biomass is being illegally harvested for charcoal and fuel wood productions in Dzalanyama forest reserve annually [19].

3.3 Uncertainty Analysis

The estimates for uncertainty for living biomass and carbon stock at 95% confidence level are presented in Table 2. The results indicates that the uncertainty for both living biomass and carbon stock were low (<4%). This is an indication that the uncertainties for estimation of biomass and carbon stock were minimized in this study. There are several sources of error in estimation of biomass and carbon stock. These include; sampling size, field measurement, and use of allometric or stem volume equations [20 – 22]. The sample size error was minimized by considering 45 plots of 0.13 ha each, totaling to 5.85 ha. It has been reported that the recommended total sample size is 5 ha or 20 plots of 0.25ha. This can allow estimation of the AGB with an error of ±10% within 95% confidence interval [21, 23, 24]. Therefore, the present study had large sampling size to minimize the error. In addition, the sample plots were uniformly distributed in the forest reserve.

The field measurement error was minimized by measuring a large amount of trees. In this study a total of 3428 trees were measured. Measuring large amounts of trees leads to measurement errors which are normally distributed and have minimal effect on the final biomass determination [23]. The use of site specific stem volume equations also contributed to minimize the uncertainty. It has been reported that site specific allometric or stem volume equations tends to have low (<5%) uncertainty [25]. Malawi is in the initial stages of REDD+ (Reducing emissions from deforestation and forest degradation through sustainable forest management) and proposed to adopt Tier 2. The use of site specific stem volume equation could also help Malawi to achieve Tier 2 level of accuracy for REDD+ framework. The recommended uncertainties for REDD+ mechanism is less than 15% at 95% confidence interval [26]. Therefore, further estimation of biomass and carbon stock for the remaining part of miombo woodland in Chongoni forest reserve is required, which could lead to recommendation for REDD+ activities to be carried out in Malawi with Chongoni forest reserve as one of the site.

Table2. *Biomass, Carbon stock and Uncertainty at 95% confidence level for miombo woodland in Chongoni forest reserve with standard errors in parenthesis*

Parameter	Density (kt/ha)	Total (kt)	Uncertainty (%)
Above ground biomass (AGB)	1.35(0.03)	405.53(7.73)	3.6
Below ground biomass (BGB)	0.34(0.01)	101.38(1.93)	3.5
Total living biomass (TLB)	1.69(0.03)	506.92(9.66)	3.7
Above ground carbon stock	0.68(0.01)	202.77(3.86)	3.5
Below ground carbon stock	0.17(0.01)	50.69(0.97)	3.5
Total carbon stock	0.85(0.02)	253.46(4.83)	3.7

4. CONCLUSION

The study has shown that there is significant amount of living biomass and carbon stock for the selected part of miombo woodland in Chongoni forest reserve. There were significant differences among dbh classes on number of stems per hectare with the small dbh class (5-14.9cm) having the highest number of stems per hectare. However, there were no significant differences between medium dbh class (15–29.9 cm) and the large dbh class (≥30cm) on number of stems per hectare, even though the large dbh class had slightly higher number of stems per hectare than the medium dbh class. The uncertainty for the estimated living biomass and carbon stock were low (<4%) at 95% confidence level. Further estimation of biomass and carbon stock for the remaining part of miombo woodland in Chongoni forest reserve is required, which could lead to recommendation for REDD+ activities to be carried out in Malawi with Chongoni forest reserve as one of the site.

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