



ESTIMATION OF TREE BIOMASS IN THREE AGE-SERIES OF *TECTONA GRANDIS* LINN. F IN GAMBARI FOREST RESERVE, NIGERIA

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ABSTRACT: Sustainable management of plantations can increase carbon sequestration potentials and contribute to climate change mitigation. However, carbon stock estimates are scarce in most tropical forests. This study estimated above- and belowground biomass and developed biomass equations for stock estimation in three age series of *Tectona grandis*, using an inventory approach. Sample plots (20m x 20m) were laid in 5-, 10-, and 15-year old *Tectona grandis* plantations. All the trees within the plots were enumerated for total height and diameter at breast height (DBH). The DBH of two trees in each age series of Teak stand that was closest to the mean DBH were selected for destructive sampling to estimate the biomass. Thus, samples of roots, leaves as well as stem discs were collected at the base, DBH, middle point and merchantable height and were oven-dried to determine the moisture content and dry weight. Inventory and biomass data were analysed using descriptive and inferential statistics at $p < 0.05$ level of significance. The biomass equations were also developed using regression analysis. The growth variables increased with age, with mean DBH of 4.43cm, 18.02cm and 21.12cm for the 5, 10 and 15-year-old stands, respectively. Similarly, the mean heights were 4.02m, 15.99m and 17.57m. Carbon stocks increased in the 5, 10 and 15-year-old stands with 81.18C/ha, 476.58C/ha and 864.88C/ha estimated respectively. The models: $\text{Log}B = -3.805 + 2.618\text{LogDBH}$; and $\text{Log}B = -34.009 + 2.316\text{LogDBH}$ gave the best fits for the 5 and 15-year-old stands, while $\text{Log}B = -2.410 + 0.481\text{LogDBH} + 2.185\text{LogH}$ gave the best fit for the 10-year-old stand. Hence, DBH and height parameters are suitable variables for developing allometric equations and predicting biomass of *Tectona grandis* in plantations.

Keywords: Carbon Sequestration, Allometry, Prediction Equations, Aboveground, Belowground

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1. INTRODUCTION

Tropical forests comprise about 40% of the total global terrestrial carbon and continue to sequester large amounts of carbon dioxide from the atmosphere. This sequestered carbon represents approximately half of gross primary productivity (Beer *et al.* 2010; Pan *et al.* 2011). Thus, increasing the amount of carbon removed and stored in forests is key to minimising CO₂ concentrations in the atmosphere and mitigation of climate change impacts (FAO2005; Gorte 2009). This has encouraged tropical reforestation with research focusing on quantifying forest carbon and monitoring carbon stocks and stock changes (Gibbs *et al.* 2007).

As the roles of forests in global carbon cycle continue to gain worldwide attention, accurate estimation of forest biomass is a prerequisite to answering the questions pertaining to the contributions of forests to climate change mitigation. Accurate and precise estimates of forest carbon stocks will provide

essential information required for determining changes in carbon pools and fluxes over time. Such information will enable policy makers, forest and conservation experts to redirect forest management strategies towards carbon sequestration as a management objective in the quest for enhancement of the forest ecosystems. However, the inadequacy of data to test-run methodologies and limited scientific knowledge on the sequestration potentials of forests in Nigeria are limiting the estimation of forest biomass (Aghimien *et al.* 2015). Therefore, this study estimated above- and belowground biomass and developed biomass equations for estimating C stock in three age series of *Tectona grandis* Linn. F. plantation.

2. MATERIALS AND METHODS

2.1. Study Area

This study was carried out in three age series of *Tectona grandis* in Gambari Forest Reserve, Oyo

state, Nigeria. The reserve is located on latitude $7^{\circ} 25'$ and $7^{\circ} 55'N$ and longitude $3^{\circ} 53'$ and $3^{\circ} 9'E$. Gambari Forest Reserve falls within the low land semi-deciduous forest belt of Nigeria and covers a totalland area of 17,984habetween River Ona on the West and the main road from Ibadan to Ijebu-Ode on the East (Figure 1). The reserve is divided into natural and plantation forests. The natural forest is made up of indigenous species such as *Terminalia spp.*, *Triplochiton scleroxylon*, *Irvingia gabonensis*, *Treculia africana*, among others while the plantation forest is made up of mainly exotic species such as

Gmelina arborea and *Tectona grandis* (Larinde and Olasupo 2011).

The topography is more or less undulating with an altitude ranging from 122m to 152m above sea level. The average annual rainfall is 1592.3mm with a high relative humidity (72– 86.5%) and high mean daily temperature of $30^{\circ}C$. The reserve is within the inter-tropical convergence zone between the North-East winds and the South-West winds with the prevailing moisture laden winds from South-West giving way to dry harmattan winds from the North-East for short periods in January (Akinyemi 1998).

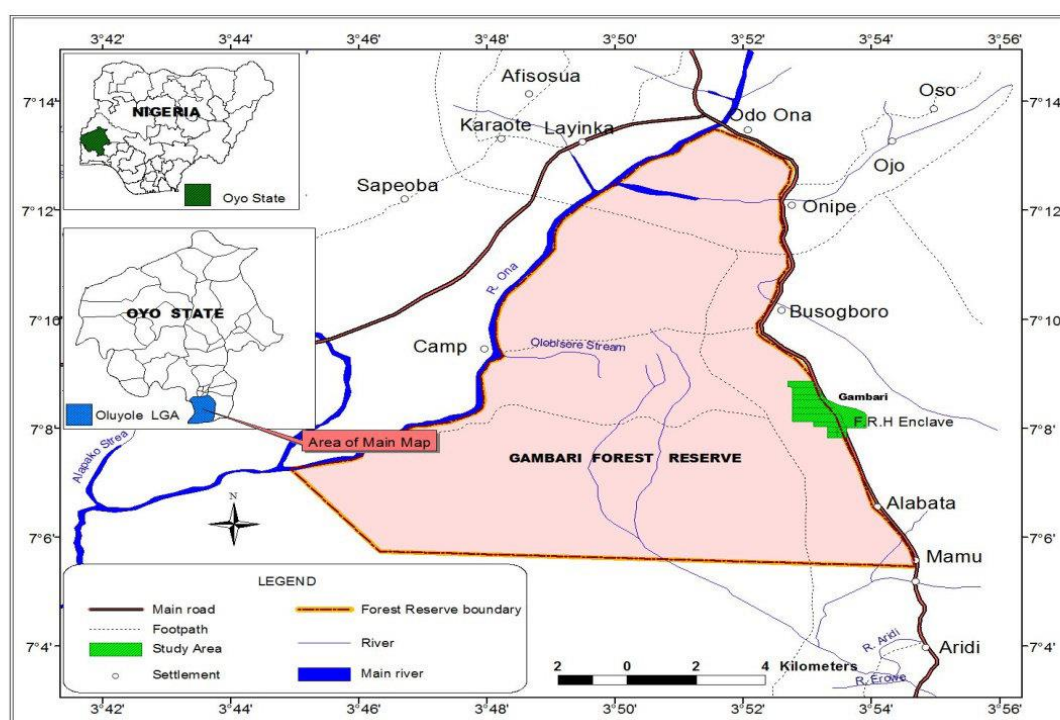


Figure 1: Map of Gambari Forest Reserve showing settlements and the planted forest area (Ige *et al.* 2013)

2.2. Sample Plot Demarcation and Measurement of Growth Variables

In the Teak plantations, 20m x 20m sample plots were laid in each age series of 5, 10 and 15-year old stands. Then, the total height (m) and diameter at breast height (dbh, cm) of all trees within each plot were measured. A mean dbh was computed and two trees with the values closest to the mean dbh were selected in each plot for biomass determination. The selected trees were felled at stump height. The roots were traced and stumps excavated, weighed and included in the total weight of the felled tree. All branches, leaves and twigs were trimmed off the main bole and weighed.

The heights of the felled trees were measured on the ground before the main bole was cut into smaller sections (at the dbh, middle and top height positions) and then weighed. Then, Discs (4cm thick) were

collected from the base, dbh, middle height and top heights of the main stem. By centralizing the stump, the roots were excavated within a $2m^2$ area around the stump. All excavated root samples were cleaned and weighed, and then representative sub samples of roots within the four quarters of the $2m^2$ area around the stump were collected for dry weight determination following the method of Olajuyigbe *et al.* (2012). Wet weight of all the subsamples which included stem discs, leaves and branches (from the dbh, middle and top heights points of the main bole) as well as roots were determined using a top-loading machine before determining their dry weight in the laboratory.

2.3. Biomass and Carbon Stock Estimation

The mean biomass was used to estimate the total biomass of trees in each plot by multiplying it with the total number of trees in the plot. Then, the per plot

biomass value was extrapolated to per hectare basis. Carbon is estimated to be approximately 50% of the live biomass stored in the aboveground and belowground plant parts (Malhi *et al.* 2009). Thus, the biomass values were converted to their carbon stock equivalent using a default value (0.5) as shown in equation 1.

$$\text{CarbonStock} = \text{TotalBiomass} \times 0.5 \dots \dots \dots (1)$$

2.4. Biomass Equations

Biomass equations were developed to estimate biomass and carbon stocks in the three-age series using the exponential model expressed in Equation 2 which was initially fitted to the data to predict individual tree biomass from DBH (cm), height (m) and age (years). Afterwards, the exponential model was linearized (Equation 3).

$$B = aDBH^b \dots \dots \dots (2)$$

$$\ln Y = \ln(a) + b * \ln(DBH) \dots \dots \dots (3)$$

Where: B=Biomass (kg), DBH = Diameter at Breast Height (cm), a and b are the regression coefficients.

2.5. Data Analysis

Analysis of Variance was used to test for significant differences among the biomass, DBH and tree total height across the age series. The mean of significantly different variables was separated using the Duncan Multiple Range Test (DMRT) while Pearson's Product-Moment Coefficient of Correlation Analysis was used to test the strength of association between tree variables (DBH and biomass). Regression analysis was used to develop biomass prediction equations.

3. RESULTS AND DISCUSSION

3.1 Results

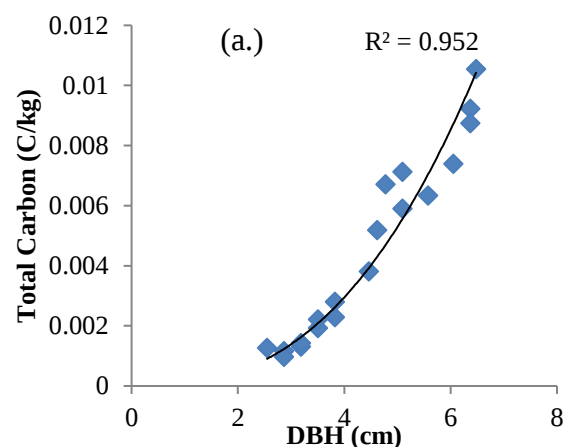
3.1.1 Growth variables

The growth variables increased with age, with mean DBH ranging from 4.43cm, to 21.12cm while mean total height ranged from 4.02m to 17.57m (Table 1). There were significant differences in the DBH ($p < 0.001$), tree height ($p < 0.001$), basal area ($p < 0.001$) and volume ($p < 0.001$) across the age series.

Table 1: Growth variables of three age series of *Tectona grandis* in Gambari Forest Reserve (N = number of tree sampled)

Variable	DBH (cm)	Total Height (m)	Basal Area (m ²)	Volume (m ³)
15-year-old stand (N=17)				
Minimum	9.80	11.00	0.008	0.084
Maximum	27.60	24.50	0.060	1.129
Mean	21.12	17.57	0.037	0.082
Standard Deviation	5.44	3.29	0.017	0.338
10-year-old stand (N = 22)				
Minimum	9.70	11.00	0.008	0.084
Maximum	25.70	22.00	0.052	0.886
Mean	18.02	15.99	0.023	0.043
Standard Deviation	3.87	2.59	0.011	0.202
5-year-old stand (N = 19)				
Minimum	2.50	2.00	0.001	0.001
Maximum	6.50	6.50	0.003	0.018
Mean	4.43	4.02	0.002	0.001
Standard Deviation	1.30	1.25	0.001	0.005

There was a strong positive relationship between tree carbon stock and DBH (Figure 2). The C stock tended to increasing with increasing DBH within each stand. In the same vein, total biomass increased with increasing total height but later dropped even as height continued to increase (Figure 3a). However, total biomass had a positive linear relationship with tree volume (Figure 3b). That is, the higher the tree volume, the higher the biomass of the trees across the three-age series. It was observed that increase in age resulted in a distinct rise in carbon stocks across the age series (Figure 4).



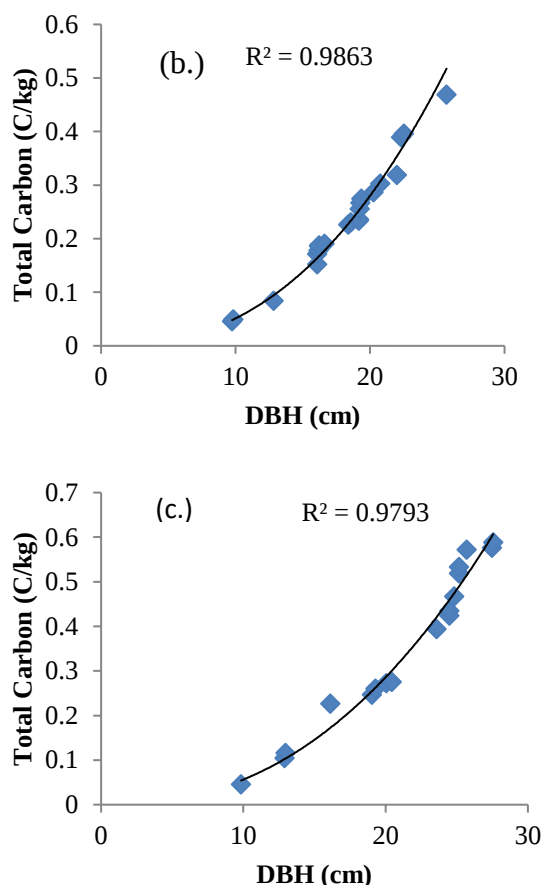


Figure 2 a, b, c. Relationship between total carbon and DBH of *Tectona grandis* in 5-, 10- and 15- year old stands at Onigambari Forest Reserve

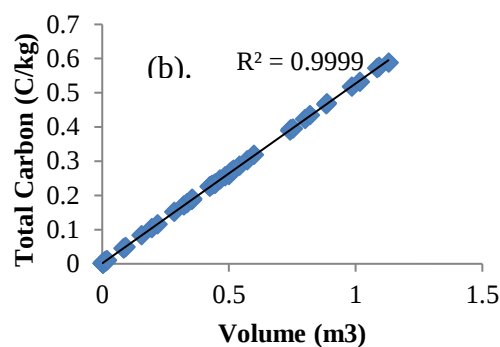
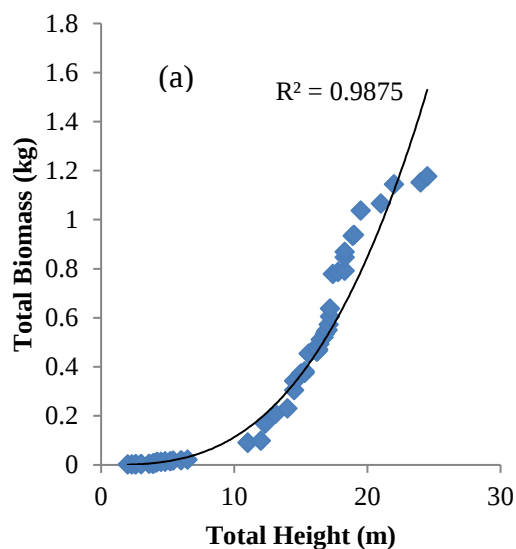


Figure 3. Relationship between (a) total biomass and total height; (b) total carbon and tree volume of *Tectona grandis* in Gambari Forest Reserve (pooled data)

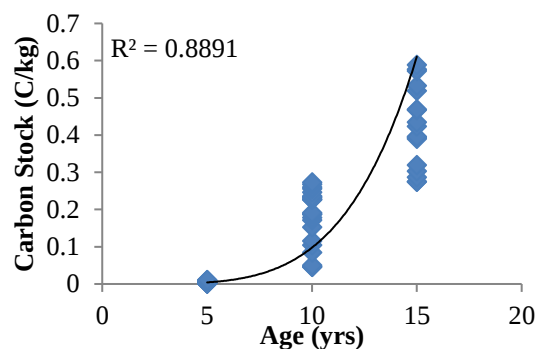


Figure 4. Carbon stocks in three age series of *Tectona grandis* in Gambari Forest Reserve

3.1.2 Biomass equations

The correlation matrix revealed that that DBH had the strongest positive correlation with biomass. The biomass values of the sampled trees ranged from 0.31 to 4.32kg of dry matter. The carbon stocks observed in the three-age series ranged from 81.18kg/ha to 864.88kg/ha, with the aboveground biomass accounting for 73.1% while belowground biomass accounted for 26.89% of the total carbon stocks (Table 2). The logarithm model with DBH as predictor of biomass produced the best fit in the 5 and 15-year-old stands, while the equation using combined DBH and height produced the best fit for the 10-year-old stand (Table 3). Analysis of the residuals for the untransformed data showed that variance was not constant as assumed, hence the need for transformation (Figure 5).

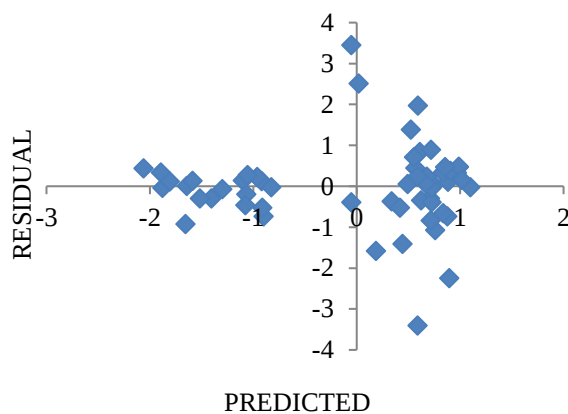
Table 2. Biomass partitioning and carbon stocks in three age series of *Tectona grandis* in Gambari Forest Reserve

Age (years)	Aboveground Biomass (kg/ha)	Belowground Biomass (kg/ha)	Total Biomass (kg/ha)	Total Carbon stock (kg/ha)
15	1229.53	500.03	1729.75	864.88
10	754.88	198.28	953.15	476.58
5	95.71	66.74	162.45	81.18

Table 3. Model statistics and coefficients of biomass prediction equations for three-age series of *Tectona grandis* in Gambari Forest Reserve.

Age (years)	Model function	R ²	S. E. E.	β_0	β_1	β_2
5	$\text{Log}B = \beta_0 + \beta_1 \cdot \text{LogDBH}$	0.952	0.079	-3.805	2.618	
10	$\text{Log}B = \beta_0 + \beta_1 \text{LogDBH} + \beta_2 \text{LogH}$	0.253	0.236	-2.410	-0.481	2.185
15	$\text{Log}B = \beta_0 + \beta_1 \cdot \text{LogDBH}$	0.957	0.067	-3.256	2.316	
After data transformation	$\text{Log}B = \beta_0 + \beta_1 \text{LogDBH}$	0.942	0.224	-3.786	2.840	
	$\text{Log}B = \beta_0 + \beta_1 \text{LogDBH} + \beta_2 \text{LogH}$	0.981	0.181	-.3868	1.392	1.456

DBH = Diameter at Breast Height, H = Tree Total Height, S.E.E. = Standard Error of Estimates $\beta_0, \beta_1, \beta_2$ are coefficient estimates,

Figure 5: Relationship between residual and predicted values of total biomass for three age series of *Tectona grandis* in Gambari Forest Reserve

3.2 Discussion

3.2.1 Growth variables as predictors of tree biomass

The basal area is a good predictor of biomass and carbon stock because it integrates the effect of both the size and number of trees (Burrows *et al.* 2000). In this study, the basal area and tree volume were strongly correlated with DBH indicating a healthy growth relationship in the plantation. Sarmiento *et al.* (2005) opined that a correlation between variables is expected because biomass and basal areas are related to trunk diameter. Thus, these relationships could be explored in estimations of biomass in forest ecosystems (Burrows *et al.* 2000).

Nevertheless, age has a strong effect on tree biomass and volume because annual height growth is characterised by the occurrence of maximum increment and the volume expresses the tree vigour in forests (Waring *et al.* 2015). However, the height and

diameter increment did not coincide, with height development moving at a different pace to diameter increment. The youngest stand significantly varied from 10 and 15-year old stands in both biomass and volume. This is because plantations with higher age series have higher biomass. Thus, older trees have higher trunk diameter with resulting increment in biomass and carbon stock (Khanduri *et al.* 2008).

3.2.2 Biomass estimation

Destructive sampling was adopted in this study because it gives a clear representation of the biomass and carbon stock in the forests (Kettering *et al.* 2001). The results revealed that biomass and carbon stock increased across the three-age series from 5-year-old stand to 15-year-old stand. Thus, 475 trees/ha in the 5-year stand accounted for 5.7% of carbon stock. 550 trees/ha in the 10-year old stand accounted for 33.50% of carbon stock while 425 trees/ha in 15-year old stand accounted for 60.97% of the carbon stock in the Teak plantation at Gambari forest reserve. This implies that age is a factor in the carbon sequestration potential of a growing plantation, with possible increase in the CO₂ captured and stored as the plantation ages.

3.2.3 Biomass prediction equations

Current global interest in forest carbon cycles continues to encourage the development of tree biomass models. However, great effort is required before accurate and consistent forest carbon stock estimates can be documented, especially with high variations that exist in different ecosystems (Waring *et al.* 2015).

Biomass equations are essential tools for predicting biomass and carbon stocks in forests with the

regression equations being fitted for each component of carbon storage. In this study, DBH showed great promise as a predictor of tree biomass and carbon stock. This corroborates Chave *et al.* (2004) who noted that one of the most important predictors of tree biomass in tropical forests was diameter at 1.3m tree height. The DBH accounted for over 95% of the variation in tree biomass and this agrees with Gibbs *et al.* (2007) who reported that DBH explained over 90% of the variation in the aboveground tropical forest carbon stock. Other tree variables with potentials are tree total height and a combination of DBH, total height and age.

Losi *et al.* (2003) opined that carbon stock estimates in forest plantations are based on allometric equations associated with the diameter at breast height. Thus, the use of the equation that employed DBH to generate biomass and eventually carbon stock in this study is an acceptable technique. Another approach that has been canvassed is the use of log-transformed linear models for estimating biomass. Many authors have noted that non-linear power functions are very important mathematical models in biomass studies, these functions are linearized using logarithm transformation (Niklas 2006).

Although log transformation does not necessarily provide a better fit of data to regression models compared to non-linear techniques, the final model choice should be based on analysis of residuals. In this study, however, log transformed data resulted in a better fit than non-linear models on the basis of goodness of fit parameters. The biomass prediction model was in the form: $\text{Log}B = \beta_0 + \beta_1 \text{LogDBH} + \beta_2 \text{LogH}$. The DBH model gave the best fit in the 5-year-old stand ($\text{Log}B = -3.805 + 2.618 \text{LogDBH}$) and the 15-year-old stand ($\text{Log}B = -34.009 + 2.316 \text{LogDBH}$). While the combined DBH and height model gave the best fit in the 10-year-old stand ($\text{Log}B = -2.410 + 0.481 \text{LogDBH} + 2.185 \text{LogH}$).

4 CONCLUSION

1. The increased interest in carbon sequestration potentials of plantations has necessitated the carbon stock estimation, particularly in tropics. This study provided baseline assessment that could enhance forest carbon budget assessment.
2. Tree biomass and carbon stocks increased with the age of the stands and thus suggested that the sequestration capacity of the plantation was positively influenced by the stage of development.
3. Diameter at Breast Height was a major independent variable required for the prediction of tree biomass and carbon stock in the three age-series of *Tectona*

grandis Linn. F. in Gambari Forest Reserve, Nigeria.

4. Further studies that would include soil carbon stocks and other age series are required to validate the applicability and accuracy of the estimated models.

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