# Allometric Models for Biomass Estimation in Savanna Woodland Area, Niger State, Nigeria

Abdullahi Jibrin, Aishetu Abdulkadir

***Abstract*—**The development of allometric models is crucial to accurate forest biomass/carbon stock assessment. The aim of this study was to develop a set of biomass prediction models that will enable the determination of total tree aboveground biomass for savannah woodland area in Niger State, Nigeria. Based on the data collected through biometric measurements of 1816 trees and destructive sampling of 36 trees, five species specific and one site specific models were developed. The sample size was distributed equally between the five most dominant species in the study site (*Vitellaria paradoxa, Irvingia gabonensis, Parkia biglobosa, Anogeissus leiocarpus, Pterocarpus erinaceous*). Firstly, the equations were developed for five individual species. Secondly these five species were mixed and were used to develop an allometric equation of mixed species. Overall, there was a strong positive relationship between total tree biomass and the stem diameter. The coefficient of determination ($R^2$ values) ranging from 0.93 to 0.99 $P < 0.001$ were realised for the models; with considerable low standard error of the estimates (SEE) which confirms that the total tree above ground biomass has a significant relationship with the dbh. *F*-test values for the biomass prediction models were also significant at $p < 0.001$ which indicates that the biomass prediction models are valid. This study recommends that for improved biomass estimates in the study site, the site specific biomass models should preferably be used instead of using generic models.

***Keywords*—**Allometriy, biomass, carbon stock, model, regression equation, woodland, inventory.

## I. INTRODUCTION

WITH increasing $CO_2$ in the atmosphere, there is an urgent need of reliable biomass estimates and carbon pools in tropical forests, most especially in Africa where there is a serious lack of data [1]. The Kyoto protocol requires transparent reporting of forest biomass changes which implies the use of precise procedure to quantify forest biomass and its uncertainty [2]. Allometric models are important for quantifying biomass and carbon storage in terrestrial ecosystems. Such models quantify the relationships between different dimensions of individual organisms [3], [4]. Field-based forest methodologies require allometric equations to estimate forest biomas/carbon from indirect measurements because direct measurement of forest carbon is costly and destructive. The allometric equations generally relate the size of an easily measurable part of a tree, e.g. the diameter of a tree trunk over bark at a specified height to the total dry weight of the tree [3].

The development and application of allometric equations is the standard methodology for aboveground tree biomass estimation [5]-[7]. However, measurement methods for carbon storage in tropical forests are still evolving [8]. At regional scales, current allometric data for complex, diverse tropical forests are almost entirely based on Southeast Asian [3], [4] and South American measurements [8]. For instance, [3] and [6] reported a set of allometric equations for tropical world forests; however, several sites were not well typified in this dataset. The foregoing background motivated this current study in the savannah woodland area of Niger state, Nigeria.

Allometric biomass models are regression equations that provide a relationship between tree fresh weight biomass and a tree dimension(s) such as dbh, or tree height [3]. To facilitate carbon stock accounting and verification, predictive models are required to provide the basis for more accurate estimates [3], [9]. A number ecozone specific allometric model would therefore be required to match the variability in tree biomass across all ecological zones and vegetation types. Consequently, allometric equations are preferably species-specific and locally derived [1]. According to [10], the literature review revealed that very few studies providing allometric equations have been conducted in Africa. Besides, the few available allometric models are very narrow in geographical coverage and scope [3], [11]-[13]. In addition, most of these models included few species or only sampled a few trees [13], [3], [14]. Consequently, the inherent variability in environmental conditions within a single eco-zone such as savannah will obviously affect how well an allometric model applies to all locations within that zone. There is therefore, the need for refined version of allometric models [3], [2]. This necessitates regional site specific allometric models which is currently lacking in the study area. The aim of this study is to develop allometric models for predicting aboveground biomass in the savannah woodland area of Niger State.

The conceptual framework for this study is based on the allometric scaling theory. Allometry is the relation between the size of an organism and the size of any of its parts [15]-[17]. The allometric scaling theory suggests the existence of a universal power-law relationship between tree biomass and tree dimension(s) with a fixed scaling exponent close to 8/3. Allometric models are regression equations derived from mathematical functions that relate oven-dry biomass per tree as a function of a single or a combination of tree dimensions [3], [5].

Abdullahi Jibrin is with Department of Geography, Ahmadu Bello University, Zaria, Nigeria (Tel: +2348036978420; e-mail: abdullahi717@hotmail.com).
Aishetu Abdulkadir is with Department of Geography, Federal University of Technology, Minna, Niger State, Nigeria (e-mail: abuzaishatu@gmail.com).

ISSN: 2517-942X
Vol:9, No:4, 2015

## II. Materials and Methods

### *A. Study Area Description*

The study was conducted in Kpashimi Forest Reserve which is located between latitude 8° 40' to 8° 52 ' North and longitude 6° 39 ' to 6° 49 ' East; covering land area of approximately 213.101 square kilometres, in Niger State, Nigeria The study area lies within the tropical hinterland climatic belt of Nigeria; characterised by alternating wet and dry season; coded as 'Aw' by Koppen's classification. The mean annual rainfall is about 1,400 mm while mean annual temperature is about 28°C [18]. The terrain of the study area strongly reflect the nature of the underlying bedrock (sedimentary rock) characterised by nearly levelled terrain, dotted by flat topped hills that rise as high as 600 meters. Generally, the altitude of the reserve is about 500 meters above sea level [19]. The most frequently encountered soil types are *ferruginous tropical soils,* on deeply weathered basement complex rocks and sandstones while *hydromorphic soils* are found on flood plains [20], [21]. Phytogeographycally, the study area is characterised by woodland savannah vegetation with the understory dominated by annual grasses [21], [22].

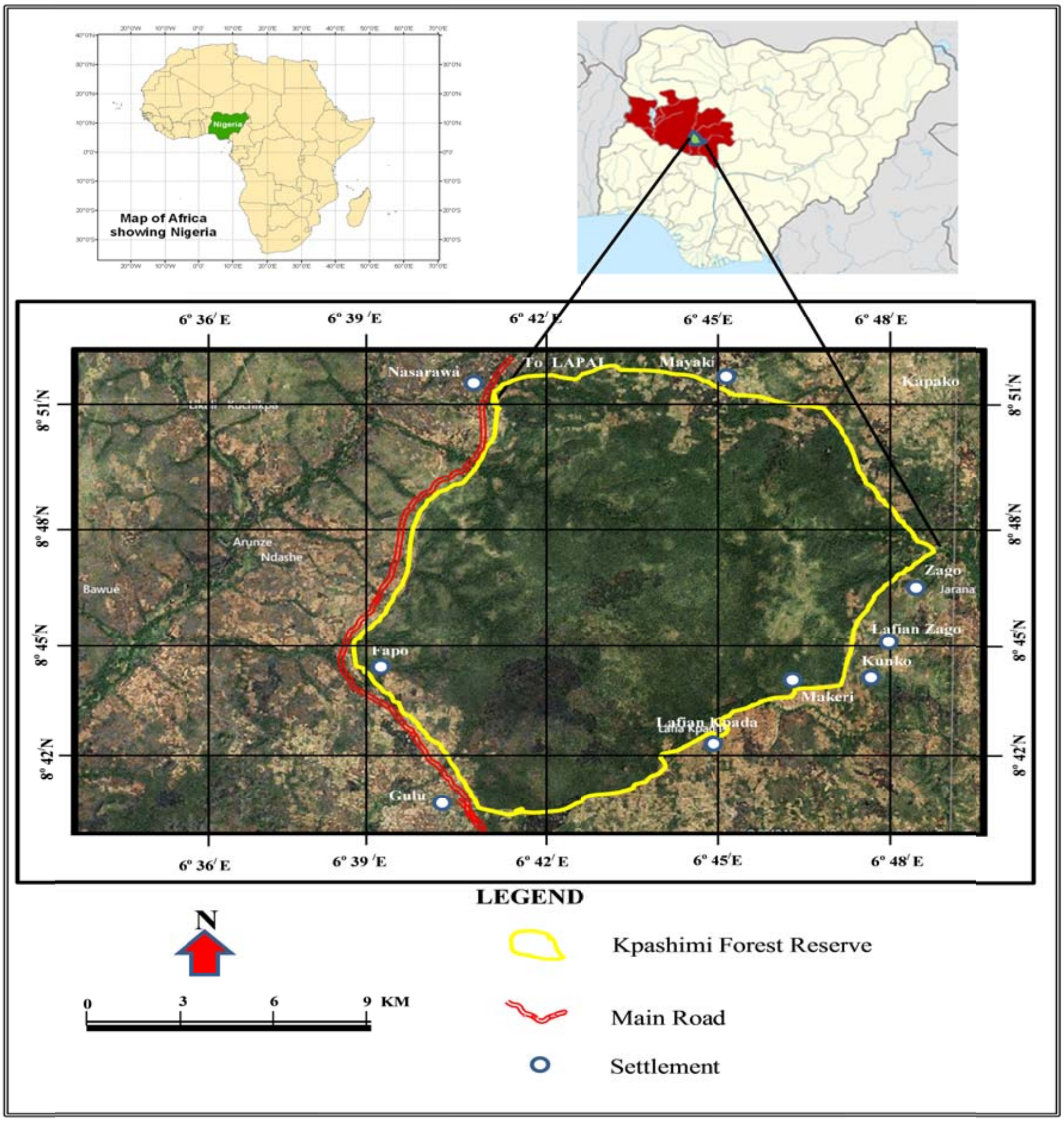


Fig. 1 The location of Study Area

### *B. Biomass Inventory Technique*

Allometric biomass equations were established through the measurement of the variable of interest (diameter at breast height) coupled with destructive sampling of biomass and statistical modelling. The fieldwork on data collection took place from September to October, 2013. A total of 1816 tree with dbh ≥ 4cm were inventoried. Destructively sampled trees were selected based on their dbh and species importance or dominance in the plant community.

For species selection, five most dominant tree species in the study area were selected for destructive sampling based on the plant Species Importance Value (S.I.V.) developed by [23]. Table I shows the five most abundant species in the study area.

TABLE I
THE FIVE MOST ABUNDANT SPECIES IN DECREASING ORDER OF THE SPECIES IMPORTANCE VALUE INDEX (S.I.V.).

| S. No. | Species Name | Relative density | Relative dominance | Relative frequency | S.I.V. |
|---|---|---|---|---|---|
| 1 | *Vitellaria paradoxa* | 13.82 | 13.08 | 5.84 | 32.73 |
| 2 | *Irvingia gabonensis* | 9.20 | 15.94 | 3.24 | 28.38 |
| 3 | *Parkia biglobosa* | 8.04 | 9.84 | 5.32 | 23.20 |
| 4 | *Anogeissus leiocarpus* | 7.65 | 9.32 | 4.67 | 21.64 |
| 5 | *Pterocarpus erinaceous* | 7.43 | 4.02 | 4.28 | 15.73 |

For the determination of dbh range of the species, dbh data from field measurements was used. Frequency table was prepared using 10cm class intervals. The tree with a dbh close to the mean dbh value for each class was then determined.

Table II indicates the mean dbh of trees across the classes for all five selected species that were harvested for destructive sampling and biomass estimation.

TABLE II
FOREST RESERVE DBH CLASS GROUPS

| Class Intervals | Frequency (N) | Percent | Girth (CM) | Mean DBH (CM) |
|---|---|---|---|---|
| 1-10.4 | 211 | 11.6 | 22.6 | 7.2 |
| 10.5-20.4 | 490 | 27.0 | 52.8 | 16.8 |
| 20.5-30.4 | 544 | 30.0 | 78.2 | 24.9 |
| 30.5-40.4 | 461 | 25.4 | 110.5 | 35.2 |
| 40.5-50.4 | 101 | 5.6 | 136.0 | 43.3 |
| 50.5-60.4 | 9 | .5 | 175.2 | 55.8 |
| Total | 1816 | 100.0 | | |

Fig. 2 Felling of sample tree

Fig. 3 Cutting of sample tree

Fig. 4 Sorting of trees component parts

A total of 36 sample trees were measured, felled and weighed. The 36 sample trees were distributed equally (Six sample trees per Species). Once a desired species with specified mean diameter was identified in the field, the plot was visited for harvesting. Before felling, species name of trees were identified and the diameter at breast height (dbh) and height were measured. Trees were felled at ground level (at 0.3 m) with machete or chainsaw according to tree size and split into fractions (see Fig. 2). The branches, and leaves were separated from the trunk and the above ground portion of each sample tree was divided in to three components viz stem, branch, and leaf (see Figs. 3 and 4). Stems and branches were trimmed and cross cut into manageable billets ranging from 1 to 2.5 m in length. Thereafter, fresh weight of each component was measured immediately, with the aid of hanging bipod spring balance scale (see Fig. 5). Leaves were collected into separate bundles where the green weight of each was weighed. Small subsamples from each bundle were collected, labelled and measured for green weight analysis in the laboratory. Subsample of stem, branch, and leaf, approximately 200 g each were extracted as discs or aliquots (see Fig. 6), labelled, for determination of their oven dry biomass in laboratory (see Fig. 7). This was later was used to calculate total dry weight of each component. Total dry weight (TDW) of each organ of sample tree was calculated from its total fresh weight (TFW), the fresh weight of its organ sample (SFW) and its dry weight of sample (SDW) based on:

$$TDW = \frac{SDW}{SFW} \, x \, TFW \quad (1)$$

Fig. 5 Trimming into billets and weighing

Fig. 6 Subsample aliquots

Fig. 7 Oven drying of aliquots

Total tree biomass was computed as a sum of stem, branches and leaves biomass. Appendix I, table V, shows the biomass data of the 36 trees felled, sorted, oven dried and weighed for this study. Out of the 36 trees harvested, 6 selected sampled trees (covering the respective species and dbh range) were set aside for model validation while the remaining sampled trees were used to fit the biomass models as shown in Figs 8-12.

*C. Allometric Equations*

The relationship between tree weight (W in kg) and stem dbh (D in cm) was best described by an exponential curve:

$$W = a^{*}D^{b} \quad (2)$$

where *a* and *b* are the regression constant and coefficient, respectively. The two sided log transformation converts the exponential model to a linear form:

$$Log_e\,(W) = Log_e\,(a) + b^{*}\,Log_e\,(D) \quad (3)$$

The log transformation was carried out using a natural logarithm in order to correct for non-linearity and heteroscedascity exhibited by the variables. The transformation equalized the variance over the entire range of biomass values which satisfies the prerequisite of linear regression [24].

Based on the log transformed data from the sampled trees, species-specific biomass prediction models for the estimation of aboveground tree biomass were developed as a function of the independent variable- diameter at breast height (dbh). Thereafter, the data from the species were pooled together to develop site-specific biomass prediction model for the estimation of aboveground tree biomass as a function of the independent variable- dbh.

*D. Model Validation*

The strength and the significance of the models were validated using the partitioned 20% validation dataset. Root Mean Square Error (RMSE) and *t*- test statistic were used for the general evaluation of predictive capability of the models. A low RMSE value in percentage indicates a better predictive capability of the model.

The following equation was used to calculate the RMSE:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_{0i} - X_{Pi})^2} \quad (4)$$

where, $X_{Oi}$ = Observed biomass, $Xpi$ = Predicted biomass, n = number of observations

The RMSE between observed biomass and predicted value yielded the value 17.8% which is considerably low. Paired sample *t*- test between observed biomass and predicted biomass revealed insignificant difference where $t$ (5) = -1.599, *p*-value (0.171) > 0.05. Thus, models validation shows that the developed biomass models can sufficiently be applied accordingly.

## III. Results

Analysis of individual model results is as follows:

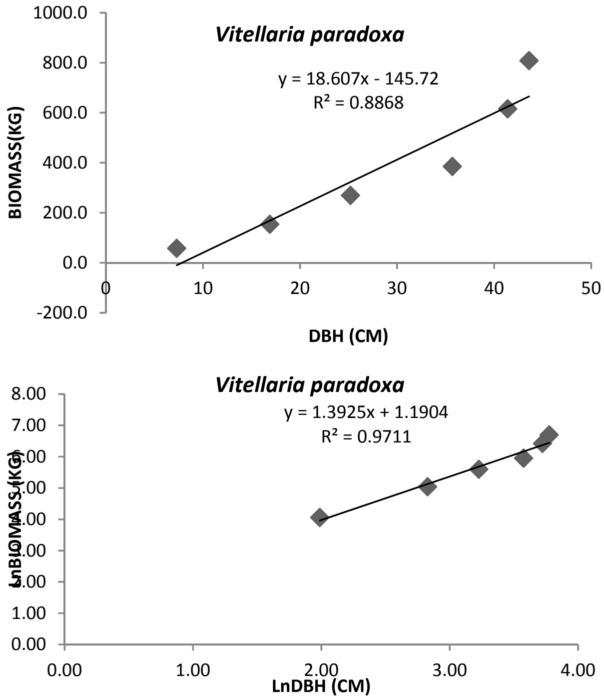


Fig. 8 Regression plots and line of best fit on raw data (top) and on logarithmic scale (bottom) for *Vitellaria paradoxa* species

The line of best fit for the log transformed aboveground biomass and dbh for *Vitellaria paradoxa* species accounted for 97% of the variability in the sample data ($R^2$= 0.97). This is confirmed by the scatter of the observations around the line of best fit in the plot shown in Fig. 8. The points lie fairly close to the line of best fit which suggests that the biomass prediction model provides a good fit to the data. The standard error of the estimate is 0.18. The results also indicate that the *F*-value for the regression model is also significantly different from zero $F(1,4)$ =134.6, P<0.001, which validates the model.

Regression graphs of the allometric model developed for *Irvingia gabonensis* species is presented in Fig. 9. The $R^2$ value of the linear model of the log transformed total tree aboveground biomass and dbh is 0.99. An $R^2$ value of 99 % is very close to 100%, and it indicates that the biomass prediction model provides a good fit to the data; confirmed by the scatter of the observations along the line of best fit. The observations are scattered very close to the line of best fit, which indicates that total tree aboveground biomass can be adequately predicted by the dbh. The standard error of the estimate is 0.06, while the results also indicate that the *F*-value for the regression model is significantly different from zero $F(1,4)$ =1147.8, P<0.001, which validates the model.

The line of best fit for the log transformed tree aboveground biomass estimated by log transformed dbh for *Parkia biglobosa* species accounted for 99% of the variability in the sample data ($R^2$= 0.99). This is confirmed by the scatter of the observations along the line of best fit in the plot shown in Fig. 10. The points lie fairly close to the line of best fit which suggests that the biomass prediction model provides a good fit to the data. The standard error of the estimate is 0.08. The results also indicate that the *F*-value for the regression model is also significantly different from zero $F(1,4)$ =601.6, P<0.001, which validates the model.

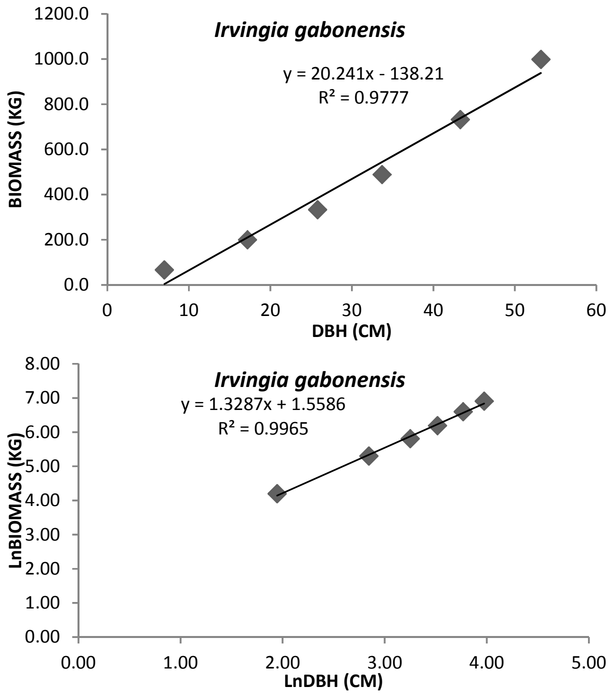


Fig. 9 Regression plots and line of best fit on raw data (top) and on logarithmic scale (bottom) for *Irvingia gabonensis* species

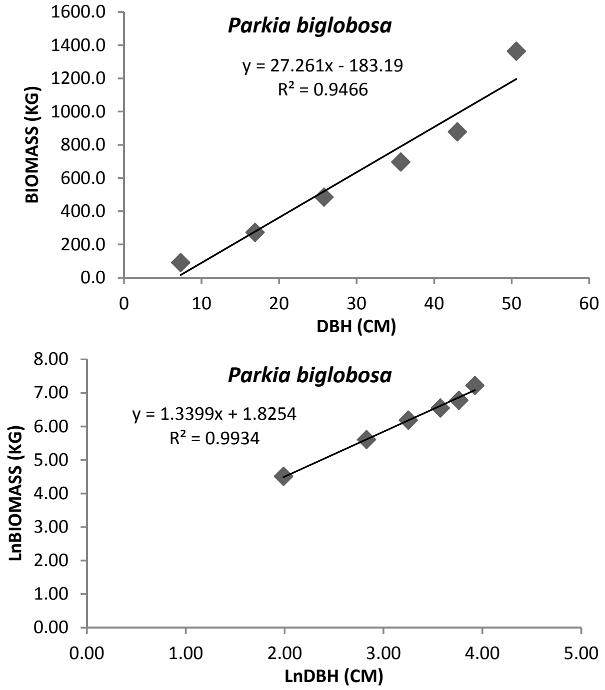


Fig. 10 Regression plots and line of best fit on raw data (top) and on logarithmic scale (bottom) for *Parkia biglobosa* species

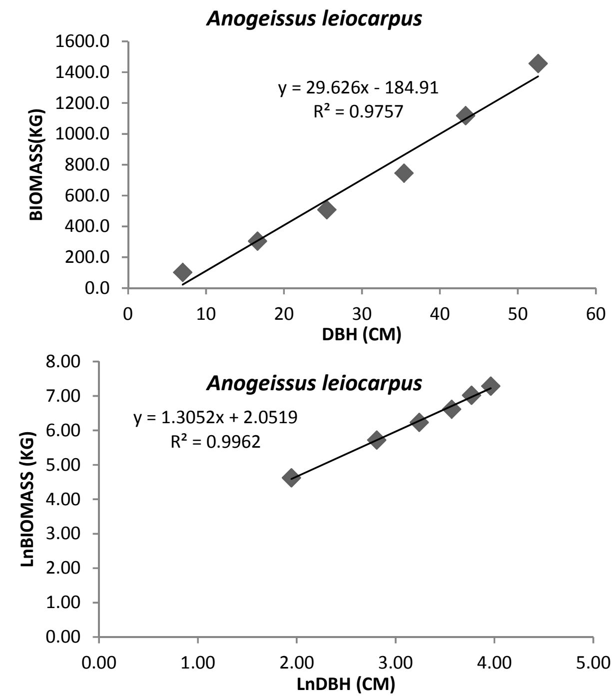


Fig. 11 Regression plots and line of best fit on raw data (top) and on logarithmic scale (bottom) for *Anogeissus leiocarpus* species

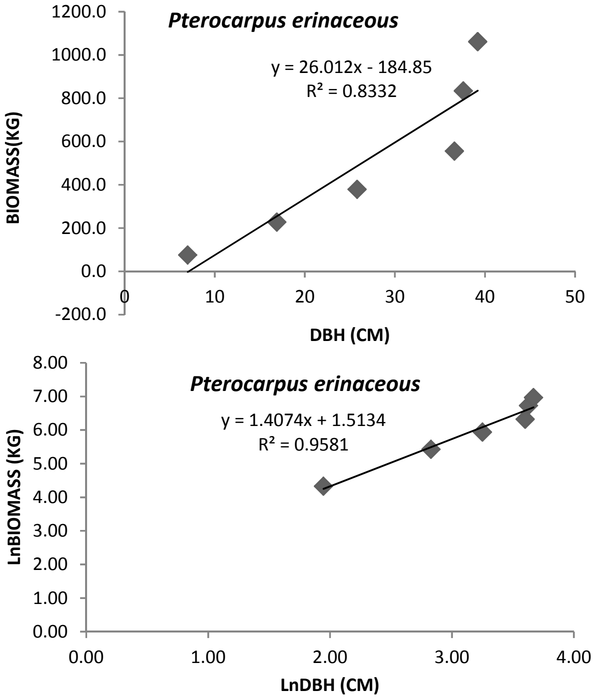


Fig. 12 Regression plots and line of best fit on raw data (top) and on logarithmic scale (bottom) for *Pterocarpus erinaceous* species

The linear model of the log transformed tree aboveground biomass against the log transformed dbh of *Anogeissus leiocarpus* species has yielded $R^2$ value of 0.99 thereby accounting for 99% of the variability in the sample data. This is confirmed by the scatter of the observations along the line of best fit in the plot shown in Fig. 11. The points lie along the line of best fit which suggests that the biomass prediction model provides a good fit to the data. The standard error of the estimate is 0.06; while the *F*-value for the regression model is also significantly different from zero $F(1,4) = 1050.3$, $P<0.001$, and therefore the model is valid.

The plot of the line of best fit for the log transformed tree aboveground biomass against the log transformed dbh of *Pterocarpus erinaceous* species showed that the observations are scattered around the regression line (see Fig. 12). This is indicative of slight variability. The linear model of the log transformed tree aboveground biomass against the pooled data of log transformed dbh yielded $R^2$ value of 0.96 thereby accounting for 96% of the variability in the sample data. The standard error of the estimate is 0.22, while the *F*-value for the regression model is also significantly different from zero $F(1,4) = 91.40$, $P<0.001$ which indicates that there is a positive linear relationship between total tree above ground biomass and the dbh and therefore the model is valid.

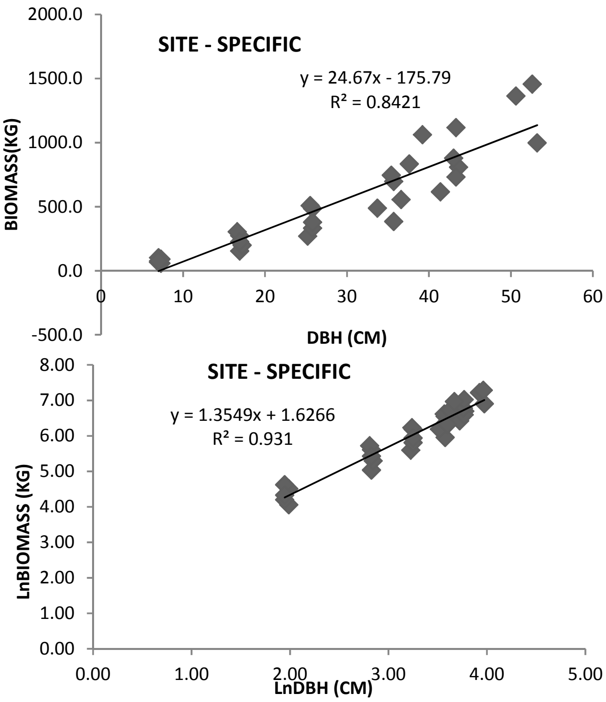


Fig. 13 Regression plots and line of best fit on raw data (top) and on logarithmic scale (bottom) for Site specific model

For the Site specific model, the line of best fit for total tree aboveground biomass estimated by dbh is presented in Fig. 13. The plot of the observations and line of best fit showed that the observations are scattered around the regression line. This is indicative of slight variability in the variety of mixed species involved. The linear model of the pooled data for the log transformed tree aboveground biomass against the pooled data of log transformed dbh has yielded $R^2$ value of 0.931 thereby accounting for 93.1% of the variability in the sample data. The standard error of the estimate is 0.25, while the *F*-value for the regression model is also significantly different from zero $F(1,28) = 377.5$, $P<0.001$ which indicates that there is a positive linear relationship between total tree above ground biomass and the dbh and therefore the model is valid.

Table III presents the coefficients and fit statistics from fitting the biomass prediction models. The coefficient of determination ($R^2$ values) ranging from 0.93 to 0.99 $P < 0.001$ were realised for the models; with considerable low standard error of the estimates (SEE) which confirms that the total tree above ground biomass has a significant relationship with the dbh. The *F*-test value for the biomass prediction models were also significant at $p < 0.001$ which indicates that the biomass prediction models are valid.

TABLE III
PARAMETER ESTIMATE AND PERFORMANCE OF DEVELOPED MODELS

| | | Parameter Estimates | | Performance Criteria | | |
|---|---|---|---|---|---|---|
| **Model Type** | **N** | $\beta_0$ | $\beta_1$ | $R^2$ | ***SEE*** | ***F-test*** |
| Site Specific (General) | 30 | 1.627 | 1.355 | 0.93 | 0.25 | F(1,28) =377.5, P<0.001* |
| Species Specific | 6 | 1.190 | 1.393 | 0.97 | 0.18 | F(1,4) =134.6, P<0.001 * |
| Species Specific | 6 | 1.559 | 1.329 | 0.99 | 0.06 | F(1,4) =1147.8, P<0.001* |
| Species Specific | 6 | 1.825 | 1.340 | 0.99 | 0.08 | F(1,4) =601.6, P<0.001 * |
| Species Specific | 6 | 2.052 | 1.305 | 0.99 | 0.06 | F(1,4) =1050.3, P<0.001* |
| Species Specific | 6 | 1.513 | 1.407 | 0.96 | 0.22 | F(1,4) =91.40, P<0.001 * |

Note: *= Statistically significant, SEE= Standard Error of the Estimate

TABLE IV
DEVELOPED SITE SPECIFIC AND SPECIES SPECIFIC ALLOMETRIC MODELS

| S. No. | Model | Species | DBH Range (cm) |
|---|---|---|---|
| 1 | AGB = exp{1.627 + 1.393 * Ln(DBH)} | General Site Species | 4<dbh<55 |
| 2 | AGB = exp{1.190 + 1.355 * Ln(DBH)} | *Vitalleria paradoxa* | 4<dbh<55 |
| 3 | AGB = exp{1.559 + 1.329 * Ln(DBH)} | *Irvingia gabonensis* | 4<dbh<55 |
| 4 | AGB = exp{1.825 + 1.340 * Ln(DBH)} | *Parkia biglobosa* | 4<dbh<55 |
| 5 | AGB = exp{2.052 + 1.305 * Ln(DBH)} | *Anogeissus leiocarpus* | 4<dbh<55 |
| 6 | AGB = exp{1.513 + 1.407 * Ln(DBH)} | *Pterocarpus erinaceous* | 4<dbh<55 |

exp {…}means "raised to the power of {…}"; Ln means "natural log of (…)"; AGB = above-ground biomass in kg; DBH = diameter at breast height (1.3 m).

An overview of the allometric models is developed in this study are shown in Table IV. The developed general (mixed species) model is recommended to be applied to savannah woodlands of where similar conditions exist as in the study site.

## IV. DISCUSSION

From the fore going analysis, above-ground biomass generally increased with increasing stem diameter. The relationship between tree weight (W, kg) and stem dbh (D, cm) was best described by an exponential curve: where *a* and *b* are the regression constant and coefficient, respectively. The observed goodness-of fit of the models investigated was in agreement to previous works on the relationship between above ground biomass and dbh [12], [3], [25], [4]. The dbh was reported to explain about 95% of the biomass [10]. Similarly, according to reference [3], dbh alone explains more than 95% of the variation in aboveground tropical forest carbon stocks, even in highly diverse regions. Reference [26] pointed out that high correlations are common in biomass equations of woody species, and may be due to the fact that stem weight represents the major proportion of above-ground biomass. Similarly, [12], [3], [4] established that determination of woody plant biomass relationships with any of a series of morphometric variables usually yields highly significant results, especially after transformation of one or both sides of the dependent and independent variables. The findings from this research quite agree with such previous findings because improvement in $R^2$ values was noticed when both sides of the dependent and independent variables used in this study were log transformed.

## V. CONCLUSION AND RECOMMENDATION

The choice of an appropriate allometric model is a critical step in reducing uncertainties in forest biomass stock estimates. This study provides a scientific contribution for accurate estimations of biomass and carbon stock in savannah woodland. Based on the data collected through destructive sampling, six allometric models were developed. Firstly, the equations were developed for five individual species selected based on their importance value index. The parameters of the biomass equations were estimated using linear least square regression. Before establishing the allometric equation, scatter plots were used to see whether the relationship between independent and dependent variables was linear. The coefficient of determination ($R^2$ values) ranging from 0.93 to 0.99 $P < 0.001$ were realised for the models; with considerable low standard error of the estimates (SEE) which confirms that the total tree above ground biomass has a significant relationship with the dbh. The *F*-test value for the biomass prediction models was also significant at $p < 0.001$ which indicates that the biomass prediction models are valid.

This work adds to the scanty but growing number of studies which demonstrate good relationships between some stem characteristics and total woody biomass in savanna woodlands, from which reliable biomass tables can be developed. The biomass prediction models derived here provide an ideal opportunity for further work on the verification of woody biomass calculations, thus leading to more meaningful estimations of standing woodland biomass stocks. This study recommends that for improved biomass estimates of study sites, the site specific biomass models should preferably be used instead of using existing generic models.

## APPENDIX I

TABLE V
DATA ON SAMPLED TREES

| S. NO. | PLOT | SPP CODE | SPECIES NAME | HEIGHT | DBH | BIOMASS (KG) |
|---|---|---|---|---|---|---|
| 1 | 15 | 55 | *Vitellaria paradoxa* | 7.1 | 7.3 | 57.8 |
| 2 | 21 | 55 | *Vitellaria paradoxa* | 12.1 | 16.9 | 154 |
| 3 | 9 | 55 | *Vitellaria paradoxa* | 16.6 | 25.2 | 269.5 |
| 4 | 3 | 55 | *Vitellaria paradoxa* | 22.3 | 35.7 | 385 |
| 5 | 30 | 55 | *Vitellaria paradoxa* | 26.1 | 41.4 | 616 |
| 6 | 3 | 55 | *Vitellaria paradoxa* | 24.4 | 43.6 | 808.5 |
| 7 | 5 | 36 | *Irvingia gabonensis* | 9.6 | 7.0 | 66.6 |
| 8 | 28 | 36 | *Irvingia gabonensis* | 12 | 17.2 | 199.7 |
| 9 | 13 | 36 | *Irvingia gabonensis* | 13 | 25.8 | 332.9 |
| 10 | 26 | 36 | *Irvingia gabonensis* | 22.2 | 33.7 | 488.2 |
| 11 | 17 | 36 | *Irvingia gabonensis* | 24.4 | 43.3 | 732.3 |
| 12 | 2 | 36 | *Irvingia gabonensis* | 39.1 | 53.2 | 998.6 |
| 13 | 15 | 43 | *Parkia biglobosa* | 8.5 | 7.3 | 90.9 |
| 14 | 29 | 43 | *Parkia biglobosa* | 12.2 | 16.9 | 272.8 |
| 15 | 7 | 43 | *Parkia biglobosa* | 16.7 | 25.8 | 485 |
| 16 | 2 | 43 | *Parkia biglobosa* | 18.4 | 35.7 | 697.1 |
| 17 | 6 | 43 | *Parkia biglobosa* | 28.2 | 43.0 | 879 |
| 18 | 26 | 43 | *Parkia biglobosa* | 27.8 | 50.6 | 1364 |
| 19 | 4 | 11 | *Anogeissus leiocarpus* | 5.6 | 7.0 | 101.6 |
| 20 | 30 | 11 | *Anogeissus leiocarpus* | 12.6 | 16.6 | 304.9 |
| 21 | 12 | 11 | *Anogeissus leiocarpus* | 16.6 | 25.5 | 508.2 |
| 22 | 23 | 11 | *Anogeissus leiocarpus* | 19.4 | 35.4 | 745.4 |
| 23 | 25 | 11 | *Anogeissus leiocarpus* | 28.1 | 43.3 | 1118 |
| 24 | 25 | 11 | *Anogeissus leiocarpus* | 32.2 | 52.6 | 1456.8 |
| 25 | 10 | 47 | *Pterocarpus erinaceous* | 8.6 | 7.0 | 75.8 |
| 26 | 20 | 47 | *Pterocarpus erinaceous* | 11.2 | 16.9 | 227.4 |
| 27 | 22 | 47 | *Pterocarpus erinaceous* | 17.7 | 25.8 | 379.1 |
| 28 | 2 | 47 | *Pterocarpus erinaceous* | 15.1 | 36.6 | 555.9 |
| 29 | 15 | 47 | *Pterocarpus erinaceous* | 9 | 37.6 | 833.9 |
| 30 | 1 | 47 | *Pterocarpus erinaceous* | 23.2 | 39.2 | 1061.3 |
| | | | VALIDATION | | | |
| 31 | 12 | 55 | *Vitellaria paradoxa* | 7.3 | 5.7 | 47.3 |
| 32 | 29 | 47 | *Pterocarpus erinaceous* | 15.6 | 12.4 | 147.5 |
| 33 | 18 | 43 | *Parkia biglobosa* | 18.6 | 22.9 | 370.7 |
| 34 | 25 | 55 | *Vitellaria paradoxa* | 20.2 | 36.6 | 640 |
| 35 | 8 | 36 | *Irvingia gabonensis* | 25.5 | 42.0 | 795.5 |
| 36 | 23 | 11 | *Anogeissus leiocarpus* | 34 | 58.9 | 1250.1 |

## ACKNOWLEDGMENTS

The financial support from Ahmadu Bello University TET fund is gratefully acknowledged. Thanks are also due to the Reviewers and Editor for their comments and suggestions. The authors are greatly indebted to all those that assisted in the collection of these data. We thank the Director (Mallam Muhammad Muhammad) and staff of the Niger State Forestry Division for their support. We are also indebted to the staff of the Kpashimi Forest Reserve, Lapai, Niger state; their cooperation and assistance which facilitated the compilation of data.

## REFERENCES

[1] UNFCCC (2006). Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol. Montreal, UNFCCC: 103.
[2] IPCC, (2006). IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories

Programme. Edited by H.S. Eggleston, L Buendia, K Miwa, T Ngara and K Tanabe. Institute for Global Environmental Strategies, Japan.
[3] Brown, S., (1997). Estimating Biomass and Biomass Change of Tropical Forest: A Primer Food and Agricultural Organisation of the United Nations (FAO), Rome.
[4] Ketterings, Q.M., Coe, R., van Noordwijk, M., Ambagau, Y. and Palm, C.A., (2001). Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. Forest Ecology and Management, 146(1-3): 199-209.
[5] Brown, S., Gillespie A. and Lugo A.E. (1989). 'Biomass estimation methods for tropical forests with applications to forest inventory data' In: Forest Science. 35 881–902
[6] Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.-P., Nelson, B., Ogawa, H., Puig, H., Riéra, B. & Yamakura, T.( 2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia. 145: 87–99.
[7] Návar, J., 2009. Allometric equations for tree species and carbon stocks for forests of northwestern Mexico. Forest Ecology and Management 257, 427-434.
[8] Cao, M. K., Q. F. Zhang, and H. H. Shugart. (2001). 'Dynamic responses of African ecosystem carbon cycling to climate change'. In: Climate Research 17:183-193.
[9] Bombelli, A., Henry, M., Castaldi, S., Adu-Bredu, S., Arneth, A., De Grandcourt, A., Grieco, E., Kutsch, W.L., Lehsten, V., Rasile, A., Reichstein, M., Tansey, K., Weber Valentini, R., (2009). The Sub-Saharan Africa carbon balance, an overview. In: Biogeosciences Discussions 6, 2085–2123.
[10] Gibbs, H.K., Brown, S., Niles, J.O. and Foley, J.A. (2007) Monitoring and estimating tropical forest carbon stocks: making REDD a reality. In: Environmental Research Letters (2).
[11] Brown, S. and A. E. Lugo, (1982) The storage and production of organic matter in tropical forests and their role in the global carbon cycle. In: Biotropica 14: 161-187.
[12] Brown, S. and A. E. Lugo, (1984) Biomass of tropical forests: A new estimate based on forest volumes. Science 223:1290-1293
[13] Brown, S. and Lugo, A. E. (1992). 'Above ground biomass estimates for tropical moist forests of the Brazilian Amazo'. In: Interciencia 17:8-18.
[14] Brown, S. and Schroeder, P. E. (1999). 'Spatial patterns of aboveground production and mortality of woody biomass for eastern U.S. forests', In: Ecological Application 9, 968–980.
[15] Huxley, J. S. (1924) Constant differential growth-ratios and their significance. In: Nature 114; 895.
[16] Huxley, J. S. (1932) Problems of Relative Growth. Methuen & Co., Ltd London
[17] Huxley, J.S., (1993). Problems of relative growth. With a new introduction by Frederick B. Churchill and essay by Richard E. John Hopkins University Press. London.
[18] Ojo, O. (1977). The climates of West Africa. London: Heinemann
[19] FORMECU (1994). Forest Management Evaluation and Co-ordinating Unit (1994) World Bank/Government of Nigeria Forestry III project Vol. VI Environmental Assessment, Forest Management Component, kpashimi Forest Reserve, Final Draft.
[20] Areola, O., (1978). Soil and vegetation resources of Nigeria. In: A geography of Nigerian development, (ed. Oguntoyinbo et al.) Heinemann Education Books Nigeria Limited.
[21] Jaiyeoba, I.A. and Essoka, P.E.(2006). 'Soils and Vegetation' In: The Middle Niger River Basin : A field course hand book. Department of Geography, Ahmadu Bello University, Zaria.
[22] Keay R.W. J. (1953), An outline of Nigerian Vegetation, 2nd Edition, Government Printed, Lagos
[23] Cottam G. & Curtis J.T.(1956). The use of distance measurements in phytosociological sampling. Ecology 37: 451-460.
[24] Sokal, R.R. and Rohlf, F.J., (1995). Biometry: the principles and practice of statistics in biological research. Third Edition, W.H. Freeman and Company, New York.
[25] Arevalo, C.B.M., Volk, T.A., Bevilacqua, E. and Abrahamson, L., (2007). Development and validation of aboveground biomass estimations for four Salix clones in central New York. Biomass and Bioenergy, 31(1): 1-12. Asner.
[26] Senelwa, K. and R. E. H. Sims. (1998). Tree biomass equations for short rotation Eucalyptus grown in New Zealand. Biomass and Bioenergy 13: 133- 140.