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Research Article

BASAL AREA - STUMP DIAMETER MODELS FOR *TECTONA GRANDIS*

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ABSTRACT
The issue of illegal tree extraction affects tropical forests in developing nations. Conviction of criminals as well as proper inventory by forest managers has been hampered by the lack of empirical ways to convey the dimensions, structure, quality, and quantity of a removed tree. In order to value timber in the event of illegal felling, this study was set out to create a model that can accurately estimate each tree's basal area (BA) from stump diameter (Ds) for *Tectona grandis* stands in the Department of Forestry and Wildlife arboretum, University of Port Harcourt. In the T. *grandis* plantation, five temporary sample plots (TSPs) measuring 20 m x 20 m were randomly placed. All T. *grandis* trees still growing in the five TSPs had their BA, Ds, and other tree growth variables measured. The mean values of the tree growth variables measured such as DBH, BA, Ds were 0.1219, 0.0131, 0.4751 respectively. Relationships among the variables were all positively correlated. The results observed from correlation matrix showed that Stump diameter (Ds) had a strong correlation with Basal area (BA) and Diameter at breast height (DBH) with correlation coefficient value of 0.94 and 0.96 respectively. Six basal area models including; Linear, single logarithmic, double logarithmic, power, growth, exponential models were fitted and evaluated. The Basal area-stump diameter relationship was best described by power model which gave least standard error of estimates (0.0027) with a high coefficient of determination (0.93). The power model was validated and it showed that there was no significant differences between the observed and predicted values and was found to be appropriate for estimating the basal area of *Tectona grandis* stands in the Department of Forestry and Wildlife arboretum, University of Port harcourt. This study showed that basal area estimation is realistic even with stump diameter as the only piece of information available.

Keywords: *Basal area, correlate, forest, stump, models*

INTRODUCTION
Forests have largely contributed to rural livelihood and economic development. In Nigeria, forests have been acknowledged as a very strong base benefiting the economy of the country and the livelihood of the rural populace (Shackleton and Shackleton, 2004). By estimation, about 90% of the poor in the world rely on forests for their income, and in Africa, an estimation of 600 million persons depend on the forest for their livelihood (Anderson *et al.*, 2006). Forest resources being very important to man is invaluable, indispensable and innumerable, having economic, social and environmental benefits. The depletion of these resources without good account has become on the high rate. There is the need to address this problem of unregulated and unsustainable harvesting by the use of appropriate stand evaluation and measurement to checkmate the removal of trees from the forest.
In Forestry practice, Basal area is of utmost importance. Basal area evaluates the average amount of an area, in terms of an acre, occupied by tree stems. Basal area of a tree is defined as the total cross-sectional area of all stems in a forest stand, measured at breast height (1.3m or 4.5ft), usually expressed as per unit of land area. Basal area is also useful for creating prudent timber harvest decisions and an important tool in understanding forest-wildlife habitat relationships. Basal area is used to translate more than just how dense a stand is, though this information is useful as forest trees do not do well when they are densely packed; basal area has its link to the stand volume of timber and growth. Therefore, it is often the basis for tasks such as forest regeneration estimation and wildlife habitat requirements (Elledge and Barlow, 2012).

The illegal and unsustainable felling of trees is a major problem in forest lands today. It is estimated that forests in the Tropics (Nigeria) are being continuously depleted at a rate of 3.5% annually (The Federal Department of Forestry, 2010). The 3.5% depletion rate is largely as a result of illegal logging activities in the forest estate (Ikumola *et al*., 2016). In recent times, due to the indiscriminate felling of trees, forest lands have reduced and this has managed to continue in several parts of the country. Nigeria once took pride in having 20% of its territory covered in natural forests, but that is no longer the case as it has dropped rapidly to 10%. Foresters may need to estimate the diameter at breast height (Dbh) of trees that have been felled and it could be that only the stumps may be left as an indicator of the size of the trees. It sometimes becomes paramount to make use of the stump dimensions to predict Dbh.

It is easy to take measurement of tree characteristics such as Diameter at breast height (Dbh) and Stump diameter (Ds) with simple instruments, little input of time and cost, giving a high level of accuracy. Stump diameter is the diameter of a tree measured at six inches (0.3m) above the ground surface level (stump height). The stump height is the point at which a tree will be cut under normal felling practices in a country or region. Stump diameter though, being an important predictor of tree diameter at breast height, has rarely been considered as an important tree parameter. It is until recent times that it has been noted as important. Stump diameter (Ds) through studies, have shown that it is highly associated with diameter at breast height (Dbh), therefore, it has been used in place of Dbh to predict most tree growth variable, especially in the situation of illegal logging (Westfall, 2010; Özçelik *et al*., 2010; Shemaki and Akindele, 2013; Chukwu *et al*., 2017). Numerous reasons such as describing the structure of a removed tree, creating historical records of past management activities, reviewing harvesting practices following tree removal, assessing damage due to catastrophic events, assessing timber harvested in a final cut or thinning that has been carried out and establishing loss due to indiscriminate and/or illegal felling, could necessitate the determination of size of removed trees (Corral-Rivas *et al*., 2007).

MATERIALS AND METHODS

Study Area

This study was carried out in the Department of Forestry and Wildlife Management Arboretum, within the University of Port Harcourt, Rivers State, Nigeria. The University of Port Harcourt is located on a land area of about 400 hectares in Obio/Akpor Local Government Area of Rivers State situated on Latitude 4.90794 and 4.90809 N and longitude 6.92413 and 6.92432 E . The dry and the wet seasons are the two seasons that the area is characterized with; the area also has a rainfall pattern distribution that is nearly all year round (Aiyeloja *et al.*, 2014). The arboretum covers a total land area of about 4226.25815 m2, located at the Abuja campus of the University and contains several tree species including *Nauclea diderrichii, Khaya ivorensis, Gmelina arborea, Tectona grandis, Treculia africana, Terminalia ivorensis* (Chima *et al*., 2016).

Sampling Technique

The sampling technique used in collecting the data was based on random sampling technique. Sample plots of 20m x 20m (0.04 hectare) in area were randomly selected for the study in order to ensure objectivity and eliminate bias.

Data Collection

Data was collected from five (5) randomly selected temporary sample plots of size, 20m × 20m (0.04ha). These plots were randomly selected from the selected tree species plantation. All the trees in the selected plots were enumerated and the numbers of trees were identified, for which 354 trees were measured across the temporary sample plots.

Measurement of Tree Variables

In each sample plot, the following tree variables (quantitative data) were measured for all trees:

1. Total tree height
2. Diameter at the base
3. Stump diameter

4. Crown diameter
5. Diameter outside bark at breast height (DBH, 1.3m above the ground)

Diameter tape was used to measure diameter outside bark at breast height and stump diameter, while clinometer and distance tape was used to measure the height and crown diameter respectively.

Data analysis

The data collected from tree measurements was processed into appropriate form for analysis statistically. Data processing included basal area estimation and crown variable estimation.

Basal area estimation

The basal area for each tree within each sample plot was estimated using the formula;

$$BA = \frac{\pi D^2}{4} ------------ Eqn. 1$$

Where BA = Basal area (m^2), π = Pi is constant (3.143), D = Diameter at breast height

Crown variables estimation

Crown projection area for each tree in the plots was estimated by measuring the crown diameter and applying it to the formula;

$$CD = \frac{D_1 + D_2}{2} ------------ Eqn. 2$$

Where CD = Crown diameter, D_1 = Diameter 1, D_2 = Diameter 2

$$CPA = \frac{\pi CD^2}{4} ------------ Eqn. 3$$

Where CPA = Crown projection area, CD = Crown diameter

Statistical analysis

Regression and correlation analysis was used to summarize the relationship between the pairs of continuous variables (BA and Dbh) and (Ds and Dbh). T-test was also used to compare between the observed and predicted values.

Development of Basal Area - Stump diameter model

For the purpose of this study, six (6) basal area - stump diameter equations were proposed as candidate models for the basal area prediction of the selected tree species in the study area. These equations are listed accordingly as linear, single logarithm, double logarithm, power, growth and exponential functions. As illustrated mathematically:

Linear model, $BA = b_0 + b_1 Ds$-------------------------------- Eqn .4

Single logarithm model, $BA = b_0 + b_1 \ln Ds$ ------------------ Eqn .5

Double logarithm model, $\ln BA = b_0 + b_1 \ln Ds$ ------------------- Eqn .6

Power model, $BA = b_0 Ds^{b1}$ --------------------- Eqn .7

Growth model, $BA = e(b_0+b_1+Ds)$ ----------------- Eqn .8

Exponential model, $BA = b0\, e(b_1 Ds)$ --------------- Eqn .9

Where; BA = Basal area (m2), Ds = Stump diameter, b0 and b1= regression parameters, e = exponential function and In = natural logarithm

Model evaluation

The candidate models formulated were evaluated based on graphical and statistical analysis of the residuals using the following criteria;

Coefficient of Determination

R^2= 1 - (RSS ÷ TSS) - - - - - - - - - - Eqn 10

where; R2= Co-efficiencnt of Determination, RSS = Residual Sum of Square, TSS = Total Sum of Square

Standard Error of Estimates (SEE)
SEE = √MSE- - - - - - - - - - - - - - - - Eqn 11
where; SEE = Standard Error of Estimate, MSE = Mean Square Error

Significance of Regression Co-efficient
A model with higher R^2, least SEE and significant overall regression as well as significant regression co-efficient was selected as best.

Model validation
All suitable models were validated with the aim of observing how reliable they are for prediction purposes. One-third of the data observed were set aside for model validation. The validation was done by testing for significant difference between the predicted value and the actual (observed) value, using paired t-test as model validation method. For the model to be acceptable or valid, it indicated that there is no significant difference ($P > 0.05$; level of significance) between the observed and the predicted values.

RESULTS AND DISCUSSION

Descriptive Statistics of Tree Growth Variables
Summary statistics of the major growth variables of *Tectona grandis* evaluated in the University of Port Harcourt Arboretum is presented in table 1. A total of 354 *Tectona grandis* trees were measured. DBH ranged from 0.0446m to 0.3236m and averaged 0.1219m. The minimum Basal area (BA) for the trees was 0.0016m^2, the maximum Basal area (BA) was 0.0823m^2, which averaged 0.0131m^2. The minimum and maximum value for Stump diameter is 0.0980m and 1.2920m respectively. Stump diameter averaged 0.4751m and the Standard deviation (SD) was 0.1688m. Crown diameter and Crown projection area averaged 4.5320m and 18.5716m^{2}respectively. The result also indicates a Total tree height minimum value of 6.7000m and maximum value of 24.1000m (Table 1).

Table 1: Summary Statistics of Tree Growth Variables

Variables	N	Min	Max	Mean	SE	SD
DBH (m)	354	0.0446	0.3236	0.1219	0.0023	0.0433
BA (m^2)	354	0.0016	0.0823	0.0131	0.0005	0.0102
Ds (m)	354	0.0980	1.2920	0.4751	0.0090	0.1688
CD (m)	354	0.5600	12.6300	4.5320	0.0936	1.7617
CPA (m^2)	354	0.2464	125.3347	18.5716	0.8444	15.8866
THT(m)	354	6.7000	24.1000	15.9100	0.1808	3.4014

DBH: Diameter at breast height; BA: Basal area; Ds: Stump diameter; CD: Crown diameter; CPA: Crown projection area; THT: Total height of tree; SE: Standard error; SD: standard deviation.

Relationship between Growth Variables and Basal Area-Stump Diameter Models
The relationship between the tree growth variables is significant as seen in Table 2. Relationship among the variables were all positively correlated. DBH is strongly correlated with Basal area (0.97) and Stump diameter (0.96), while its relationship with Crown diameter (0.44), Crown projection area (0.43), and Total tree height (0.48) showed moderate correlation. Basal area also showed strong correlation with Stump diameter (0.94), and moderate correlation with Crown diameter (0.43), Crown projection area (0.44), Total tree height (0.44). Stump diameter correlated moderately with Crown diameter, Crown projection area, Total tree height with correlation values of 0.45, 0.44 and 0.47 respectively. The table also revealed that there was a strong correlation between Crown diameter and Crown projection area (0.96) and a weak relationship between Crown diameter and Total tree height (0.22). In the same vein, Crown projection area showed a weak correlation with Total tree height (0.19) (Table 2).

Table 2: Correlation Matrix of Tree Growth Variables

	DBH	BA	Ds	CD	CPA	THT
DBH	1.00					
BA	0.97**	1.00				
Ds	0.96**	0.94**	1.00			
CD	0.44**	0.43**	0.45**	1.00		
CPA	0.43**	0.44**	0.44**	0.96**	1.00	
THT	0.48**	0.44**	0.47**	0.22**	0.19**	1.00

DBH: Diameter at breast height; BA: Basal area; Ds: Stump diameter; CD: Crown diameter; CPA: Crown projection area; THT: Total height of tree; **Correlation significant at 0.01 level

Model development

The table 3 below shows the various Basal area-Stump diameter models fitted using 236 randomly selected tree samples. All models were significant, with the Power model as the best fit having the highest $R^2$of 0.93 and lowest SEE of 0.0027; though the single log produced the least R^2 of 0.72, the double log equation having a R^2 of 0.91 produced the highest SEE of 0.2081. The Basal area ~ Stump diameter model fit curves (Fig 1), shows a predicted rise in Basal area with increase in Stump diameter.

Table 4.3: Basal Area – Stump Diameter Models of *Tectona grandis* Samples

Model	Function	R^2	SEE	RMSE	PRESS	AIC
Linear	BA = -0.013 + 0.056*Ds	0.88	0.0034	0.0028	0.0029	-2681.08
Single log	BA = 0.033 + 0.024*lnDs	0.72	0.0052	0.0052	0.0068	-2478.64
Double log	lnBA = -3.053 + 1.885*lnDs	0.91	0.2081	0.2072	10.4672	-740.953
Power	BA = 0.049*$Ds^{1.892}$	0.93	0.0027	0.0027	0.5171	-2798.16
Growth	BA = $e^{-5.595 + 2.504*Ds}$	0.87	0.0037	0.0037	3.6565	-2646.48
Exponential	BA = 0.004*$e^{2.541*Ds}$	0.87	0.0037	0.0037	3.6565	-2646.48

N = 236; R^2: Coefficient of determination; SEE: Standard error of estimate; RMSE: Root mean square error; PRESS: Predicted residual error sum of squares; AIC: Akaike information criterion; BA: Basal area (m^2); Ds: Stump diameter (m); *ln*: Natural logarithm, *e*: exponential

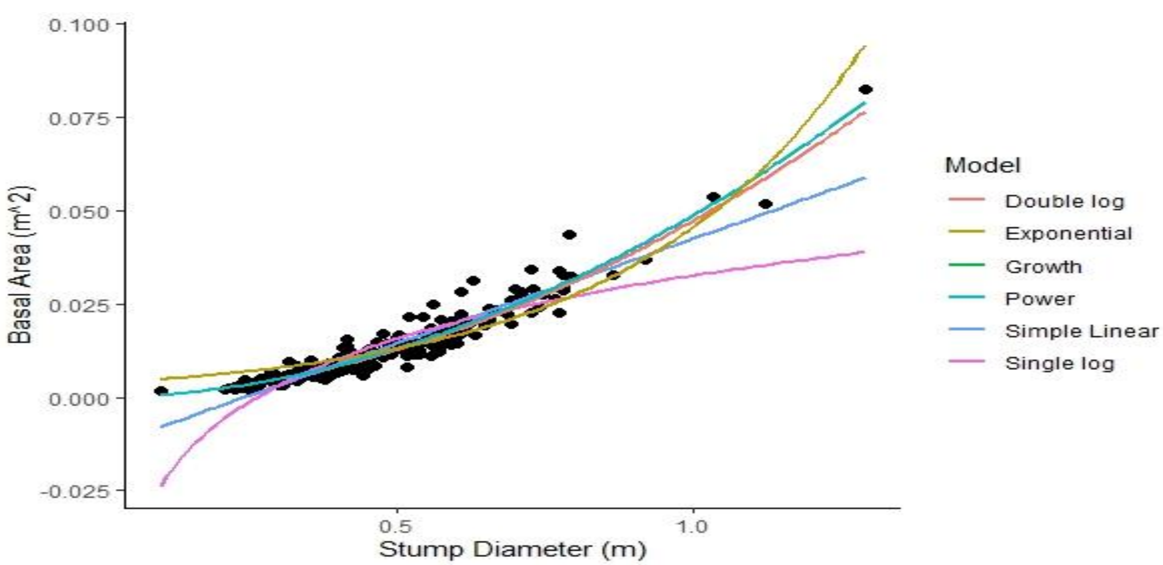

Fig. 1: Basal Area ~ Stump DiameterModel Fit Curves

Model Validation

The models were tested on the remaining 119 trees not used in the model development and the mean comparison between the actual and predicted values are presented in table 4. The t-statistics of the Simple linear, Single log, Double log, Power, Growth and Exponential models shows that there are no significant differences (P > 0.05) between the observed and the predicted values. Thus, the model is valid for predicting Basal area from Stump diameter (Table 4).

Table 4: T-test Comparison between Actual and Predicted Values of Test Samples

Model	Mean Actual	Predicted	df	t-statistics	P value
Simple linear	0.0133	0.0131	117	-0.511	0.610
Single log	0.0133	0.0130	117	-0.466	0.642
Double log	-4.5795	-4.5694	117	0.595	0.553
Power	0.0133	0.0133	117	0.048	0.962
Growth	0.0133	0.0138	117	1.409	0.161
Exponential	0.0133	0.0138	117	1.409	0.162

N = 119

Discussion

This study provided information on tree growth variables and basal area-stump diameter on *Tectona grandis* (Teak) plantation in the study area. The initial stocking at 2.5 x 2 .5 m amounted to 405 trees while the present stocking of the plantation is 354 trees. The study showed that out of the 405 *Tectona grandis* (Teak) in the plantation, 354 survived, showing a low mortality rate of 12.59% and high survival rate of 87.41% which is indicative of a moderate management. Palmer and Synnott (1992) also opined the fact that to achieve sustainability in forest management, the forest manager should have suitable knowledge of the forest stock. The summary statistics of the samples trees were presented depicting low DBH and height values. as compared to similar research conducted by Onyekwelu (2005) when developing Site Index Curves for Opepe (Nauclea didderichii) Plantation in Southwestern Nigeria who reported slightly higher values of dominant height as well as DBH, this could be as a result of variation in the ecosystem and the species involved. The mean basal area/ha reported in this study is lower than that obtained by KFRI (2015) who reported high range of basal area than that obtained in this study. The low basal area could be as a result of silvicultural management.

Correlation analysis was carried out to give an understanding of association among basal area-stump diameter and other tree growth variables before models development. The results observed from correlation matrix showed that Stump diameter (SD) had a strong correlation with Basal area (BA) and Diameter at breast height (DBH). This infers that DBH and BA increase with the increase in stump diameter. The result of the correlation further implies that, the larger the stump diameter of a tree; the larger the cross sectional area the tree's stem occupies at breast height (1.3 m). This result is in agreement with the report of Oyebade and Onyambo (2011) and Shamaki and Akindele (2013) that diameter at breast height (DBH) and stump diameter (SD) are highly correlated.

In this study effort was directed towards obtaining basal area prediction models at individual tree basis using stump diameter. Since from the correlation results, it was observed that DBH and SD are highly related, in order to avoid co-linearity between the two growth variables (SD and DBH) as indicated by Huang *et al*. (2003), only stump diameter was selected as independent variable for developing models in this study. The principle of using stump diameter alone was to help forest managers obtain information on the original structure of a forest after exploitation either by legal or illegal activities within the forest. This method was upheld by Osho (1983), Westfall (2010), Özçelík *et al*. (2010) and Shamaki and Akindele (2013) stating that, estimating tree growth variables after exploitation can only be possibly done through the stumps diameter.

The Basal area-Stump diameter models fitted in this study includes linear, single logarithmic, double logarithmic, power, growth and exponential functions. All parameters were found to be significant at the 5% level of probability. On the basis of estimated R^2 values, about 72% to 93% of the total variation in observed Basal area values was explained by Stump diameter in the six candidate models. This implies that all the candidate models had good and similar performance. The criteria adopted for selecting the best model was through comparison of R^2, SEE, and the significance of the overall model which are standard ways of verifying model fitness ability as pointed out by Li *et al*. (2002), Huang *et al*. (2003) and Shamaki and Akindele (2013).The higher the R^2value, the better the model; also the lower the SEE, the better the model. Based on the model evaluation result, the Power model was selected out of the six candidate models. Power model had the least values of SEE and the highest values of R^2. Similar result was also reported by Murphy and Shelton (1996) who modeled individual-tree basal area growth for loblolly pine. This result was also in line with the report of Tewari and Singh (2008) who developed basal area projection model for unthinned pure even-aged plantations of Eucalyptus hybrid in Gujarat State of India. Elledge and Barlow (2012) recommended prediction of basal area and further stated that, basal area determines more than just stand density; it is also linked with timber volume and tree growth. Therefore, it is often the basis for making important forest management decisions such as estimating forest regeneration needs.

Furthermore, independent data set not used in the models calibration was used to validate the model. The paired t-test was used to test for significance between predicted and the observed basal areas. The result showed that there was no significant difference. This indicates that the developed basal area-stump diameter model was valid for predicting basal area of T. *grandis* stands in the study area.

CONCLUSION

Forecasting the sizes of removed trees can be aided by estimating the characteristics of tree growth from stump diameter. The result of this findings showed that Stump diameter had a strong positive correlation with Basal area (BA) and Diameter at breast height (DBH). According to this study's assertion that stump diameter has a significant positive correlation with Dbh, stump diameter was selected as the independent variable. Conclusively, individual tree basal area can be estimated from stump diameter using the power model.

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