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Basal Area-Stump Diameter Models for *Tectona grandis* Linn. F. Stands in Omo Forest Reserve, Nigeria

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Abstract

The tropical forests in developing countries are faced with the problem of illegal exploitation of trees. However, dearth of empirical means of expressing the dimensions, structure, quality and quantity of a removed tree has imped conviction of offenders. This study aimed at developing a model that can effectively estimate individual tree basal area (BA) from stump diameter (Ds) for *Tectona grandis* stands in Omo Forest Reserve, Nigeria, for timber valuation in case of illegal felling. Thirty-six 25 m×25 m temporary sample plots (TSPs) were laid randomly in six age strata; 26, 23, 22, 16, 14, and 12 years specifically. BA, Ds and diameter at breast height were measured in all living *T. grandis* trees within the 36 TSPs. Least square method was used to convert the counted stumps into harvested stem cross-sectional areas. Six basal area models were fitted and evaluated. The BA-Ds relationship was best described by power model which gave least values of Root mean square error (0.0048), prediction error sum of squares (0.0325) and Akaike information criterion (-15391) with a high adjusted coefficient of determination (0.921). This study revealed that basal area estimation was realistic even when the only information available was stump diameter. The power model was validated using independent data obtained from additional plots and was found to be appropriate for estimating the basal area of *Tectona grandis* stands in Omo Forest Reserve, Nigeria.

Key Words: Dbh, models, Omo Forest Reserve, stump diameter, *Tectona grandis*

Introduction

Illegal logging is a major problem facing tropical forests in developing countries. The Federal Ministry of Environment (2016) estimated that Nigerian forests are being depleted at an annual rate of 3.5%. However, this depiction rate was attributed to illegal logging of timber species (Emeghara 2012; Ikuomola et al. 2016). Adebagbo (1992) reported that a in the year 1990, a total of 298 trees comprising 19 different valuable species of unknown log dimensions were illegally extracted from Supoba Forestry Reserve in Edo State of Nigeria. Lack of empirical information on the dimensions of trees removed from a forest could act as impediment in the conviction of offenders. Hence, evidence backed up with relevant facts are necessary in judicial proceedings (Evidence Act 1990).

Basal area (BA) is important tree characteristic in forestry. It is the common term used to describe the average amount of an area occupied by tree stem. However, basal area defined as the total cross-sectional area of all stems in a stand measured at breast height (1.3 m). Basal area is a useful index for making timber harvest decisions and understanding

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forest-wildlife habitat relationships. Basal area is used to determine more than just forests stand density; it is also linked with timber stand volume and growth (Barlow and Elledge 2012). Therefore, it is often the basis for making important forest management decisions such as estimating forest regeneration needs. Tree variables such as diameter at breast height (Dbh) and stump diameter (Ds) are easy to measure with simple instruments and widely used in forest inventories. However, a number of studies have shown that derived variables such as basal area, are good predictors of forest dynamics and they can improve the reliability of tools like growth and yield models. Hence, BA has received increasing attention as a means to estimate tree growth (Murphy and Shelton 1996; Chen et al. 2007).

According to Corral-Rivas et al. (2007) and Westfall (2010), numerous reasons could necessitate the reconstruction of sizes of removed trees. These reasons include; reviewing harvesting practices, assessing damage due to catastrophic events, creating historical records of past management activities and establishing loss due to indiscriminate and/or illegal felling. Previous studies have shown that tree stump diameter (Ds) is highly correlated with diameter at breast height (Dbh), and as such have being used in place of Dbh to predict most tree growth variable especially in the case of illegal logging (Osho 1983; Westfall 2010; Özçelík et al. 2010; Shamaki and Akindele 2013; Chukwu et al. 2017).

The ability to develop models that can estimate tree growth variables from stem diameter for *Tectona grandis* will guide the forester manager on the estimation of the forest stock (Shamaki and Akindele 2013), as well as quantification and valuation of a removed tree (Osho 1983; Chukwu et al. 2017). Hence, there is need to evolve a method of predicting basal area of trees from stumps, which should be accurate and easily applicable, since basal area can be used as index in the estimation of growth and yield of the forest. This can be possible by using the regression between stump diameter as independent variable and basal area as dependent variable.

However, this study aimed to develop models for predicting basal area from stump diameter for *T. grandis* plantations in Omo Forest Reserve, Nigeria, which will serve as tool in estimation of timber lost, descriptive evidence for a removed tree cross-sectional area in litigation process as well as creating historical records of past management activities.

Materials and Methods

Study area

This study was carried out at Area J4 of Omo Forest Reserve in Ijebu-Ode East local government area of Ogun State, Nigeria. The Reserve is situated between Latitude 6°35' to 7°05 N and Longitudes 4°9' to 4°40' E with a total land area of 139,100 ha. The reserve is bounded by Benin-Shagamu expressway to the south and Omo River and Oni River to the east. The Reserve lies within the equatorial belt and has a mean annual rainfall of 1,200 mm and average elevation of about 91.47 m (Alo 2016).

Tree species description

Tectona grandis (Teak) is a tropical hardwood trees species in the family Verbenaceae. The tree is deciduous, grows up to 30-40 m tall and usually large stem diameter (Robertson 2002). Teak is termed as one of the most valuable timber species in the world owned to its outstanding physical properties (vigorous, straight, single stem with slight branches that leave minimal knot formation following pruning) and timber qualities (attractiveness in colour and grain, durability, lightness with strength, ease of seasoning without splitting and cracking, ease of working and carving, resistance to termite, fungus, and weathering). Teak plantations have been widely established throughout the tropics from the 1850s, this is due to its high timber qualities which includes; market demand, ease of domestication and cultivation. The excellent properties and versatile nature of teak timber and its eminent suitability for an array of uses is well documented (FAO 1957; Kaosa-ard 1993; Miranda et al. 2011). Hence, this species was selected for this present study based on its high rate of illegal felling in the study area which has been attributed to its market demand in the world.

Sampling procedure

This study was carried out in temporary sample plots (TSPs) of *Tectona grandis* stands of different age series; 26, 23, 22, 16, 14 and 12 years specifically. A stratified random sampling technique was employed for this study. The six age series constitute the strata in the study area with a total land area of 66.5 hectare. Hence, simple random sampling technique was used in allocating thirty six (36) TSPs of 25 m×25 m size in the stands (six plots per age stratum). A total number of one thousand nine hundred and nineteen (1919) trees were measured in all the thirty six randomly selected sample plots.

Data collection

Diameter tape was used to measure individual trees diameter (over bark) at breast height (cm) and stump diameter (cm) of *T. grandis* found within the sample plots. The point of the measurement was recorded from the uphill sides of the trees and on the inside of the lean for leaning trees (Husch et al. 1982). During the measurement, loose bark, climbers and epiphytes were lifted above the diameter tape. Finally, basal area was derived from Dbh as mathematically shown below:

$$BA = \frac{\pi D^2}{4} \quad (1)$$

Where: BA=Basal Area (m^2); π=Pi is constant (3.143) and D^2=Dbh (cm)

Model description and fitting

The available fitting data consists of measurements taken from trees located within different selected plots. Least square method was used to fit data using the various candidate functions listed below. In this study, six basal area-stump diameter equations were proposed as candidate models for the basal prediction of *T. grandis* in the study area. These equations are listed accordingly as linear, single logarithm, double logarithm, power, growth and exponential functions. As mathematically shown below:

$$BA = b_0 + b_1 Ds \quad (2)$$

$$BA = b_0 + b_1 lnDs \quad (3)$$

$$lnBA = b_0 + b_1 lnDs \quad (4)$$

$$BA = b_0 Ds^{b_1} \quad (5)$$

$$BA = e^{(b_0 + b_1 Ds)} \quad (6)$$

$$BA = b_0 e^{(b_1 Ds)} \quad (7)$$

Where: BA=Basal Area (m^2), Ds=Stump diameter, b_0 and b_1=regression parameters, e=exponential and ln=natural logarithm.

Model evaluation and validation

The evaluation of the candidate models was based on graphical and numerical analysis of the residuals which are; model with least values of the standard error of estimate (RMSE), prediction error sum of squares (PRESS), Akaike information criterion (AIC) and highest adjusted coefficient of determination (Adj.R^2) was selected as best. They are mathematically expressed as follows:

$$Adj.R^2 = 1 - \frac{(1-R^2)(n-1)}{n-p} \quad (8)$$

$$RMSE. = \sqrt{\frac{\sum (Y_i - \hat{Y}_i)^2}{n}} \quad (9)$$

$$PRESS = \sum_{i=1}^{n} ([Y_i -]\hat{Y}*_{(-i)})^2 \quad (10)$$

$$AIC = n\ln(RSS/n) + 2p \quad (11)$$

Where; $\overline{Y_i}$=arithmetic mean of the observed value, Y_i=observed value of Y for observation i, $\hat{Y}_i$=predicted value

Table 1. Summary statistics of tree growth variables

Variables	Descriptive Statistics					
	N	Min	Max	Mean	SE	SD
Ds	1919	7.67	48.97	22.08	0.15	6.55
Dbh	1919	6.01	38.85	17.93	0.12	5.38
BA	1919	0.0028	0.1185	0.0275	0.0004	0.0168

Where: SD, standard deviation; SE, Standard error; BA, basal area (m^2); Dbh, diameter at breast height (cm); Ds, stump diameter (cm); N, total number of trees measured.

i, $\hat{Y}^*_{(-i)}$=predicted value of Y for observation i as calculated from a regression equation derived through fitting the p parameter model to data obtained by deleting observation i from the original data set, n=the total number of observations Y_i (trees) used in fitting the model, p=the number of model fixed parameters, RSS=Residual sum of square.

The overall best candidate model was validated using an independent data of about 25% of the data used for the model calibration and fitting. The t-test for paired samples was adopted as model validation method. In all statistical analysis, a confidence level of $p < 0.05$ was used for statistical significance.

Results

Summary statistics for tree growth variables

The data used in this study comprise of tree growth variables measured from 36 TSPs of *Tectona grandis* stands in the Omo Forest Reserve, Nigeria. A total of 1919 trees were measured and summary statistics of the data used in this study are presented in (Table 1). The distribution of stump diameter (Ds) ranged from 7.67 to 48.97cm, Dbh ranged from 6.01 to 38.85 cm and BA ranged from 0.0028 to 0.1185 m^2. The result of Pearson's product-moment correlation analysis between BA, Ds and Dbh (Table 2) revealed that Ds is highly and positively correlated with Dbh and BA (r=0.96 and 0.94 respectively). The graphical relation between the explanatory variable (Ds) versus response variable (BA) was displayed in Fig. 1. The scatter plot (graph) showed a curve-linearly relationship between basal area and stump diameter of *T. grandis* in the study area.

Table 2. Correlation matrix of tree growth variables

	Ds	Dbh	BA
Ds	1	0.96*	0.94*
Dbh	0.96*	1	0.98*
BA	0.94*	0.98*	1

*Correlation coefficient is significant at the 0.05 level (2-tailed), N=265. BA, basal area (m); Dbh, diameter at breast height (cm); Ds, stump diameter (cm).

Basal area–Stump diameter Models

The models developed in this study was to estimate the present and future values of basal area at individual tree level for *T. grandis* stands in Omo Forest Reserve, Nigeria. The models were developed using individual tree stump diameter as independent variable and basal area as dependent variable (Table 3). All parameters were found to be sig-

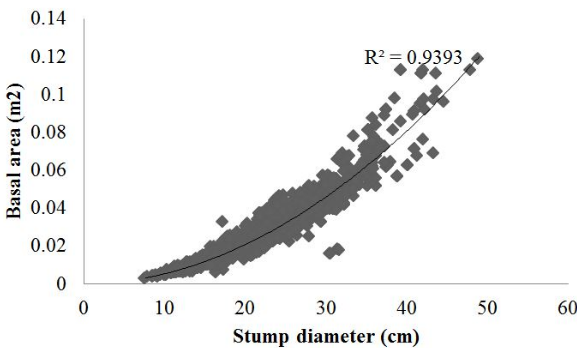

Fig. 1. Relationship between basal area and stump diameter.

Table 3. Examined Crown-Stump Diameter Models

Model Code	Function	Fit Statistics			
		Adj.R^2	RMSE	PRESS	AIC
B1	$BA=-0.026+0.002Ds$	0.888	0.0056	0.0459	-14895
B2	$BA=-0.123+0.049lnDs$	0.792	0.0077	0.0853	-14001
B3	$lnBA=-9.784+1.973lnDs$	0.947	0.1421	29.066	-5611
B4	$BA=0.0001\times Ds^{1.966}$	0.921	0.0048	0.0325	-15391
B5	$BA=e^{(-5.191+0.068Ds)}$	0.891	0.0056	0.0448	-14930
B6	$BA=0.006\times e^{(0.068Ds)}$	0.891	0.0061	0.0529	-14930

Where: Adj.R^2, adjusted coefficient of determination; PRESS, prediction residual error sum of squares; RMSE, root mean square error statistics; AIC, Akaike information criterion; BA, basal area (m^2); Ds, stump diameter; and ln, natural logarithm. N=1439.

nificant at the 5% level of probability. On the basis of estimated *Adj.*R^2 values, about 79.2 to 94.7% of the total variation in observed Basal area values was explained by Stump diameter in the six candidate models.

Out of the six models fitted using Ds as independent variable; the power model (B4) gave the least values of RMSE (0.0048), PRESS (0.0325) and AIC (-15391) and a high Adj.R^2 (0.921). However, the double logarithmic function (Model B3) gave the highest values RMSE (0.1421), PRESS (0.0325), AIC (-5611) and Adj.R^2 (0.947).

Fig. 2 showed the graph of the residuals distribution against the predicted of basal area (Model B4).

Model validation

Table 4 shows the result of the validation of the best model (equation 5).

The validation test shows that observed value was not significantly different from the predicted value of natural logarithm of basal area at probability level of 0.05.

Discussion

In this study, information on the tree growth variables (Ds and BA) from Area J4 in Omo Forest Reserve was presented in Table 1 and Fig. 1. However, correlation analysis was carried out on the dataset before models were developed to understand the association between stump diameter, Dbh and basal area. Stump diameter showed strong positive correlation with diameter at breast height and basal area. 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). Observation from the graphical analysis for basal area showed a curve linear relationship with stump diameter.

Conversely, in this study effort was directed towards obtaining basal area prediction models at individual tree basis using stump diameter. Correlation result (Table 2) revealed that Dbh was positive and highly correlated with Ds. However, this result is in congruent the report of Oyebade and Onyambo (2011) and Shamaki and Akindele (2013) that diameter at breast height (Dbh) and stump diameter (Ds) are highly correlated. Hence, to avoid co-linearity between the two growth variables (Ds and Dbh) as indicated by Huang et al. (2003), only stump 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 BA-Ds models fitted in this study were in linear, single logarithmic, double logarithmic, power, and exponential functions form (Equations 2-7, respectively). All parameters were found to be significant at the 5% level of probability. On the basis of estimated Adj.R^2 values, about 79.2 to 94.7% of the total variation in observed Basal area

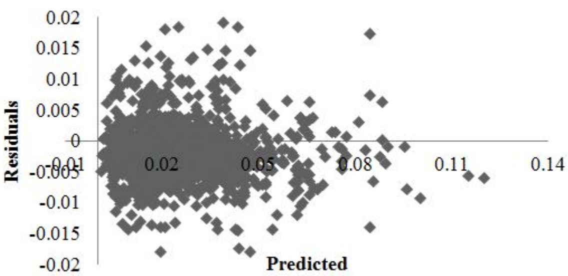

Fig. 2. Residual plot of basal area for power model (Model B4) using stump diameter as independent variable.

Table 4. Results of Validation of Model 3 using t test for Paired Sample

Variable	Mean	SD	Diff	t	Df	p	Remark
Cd Observed	0.02694	0.01646					
Cd Predicted	0.02653	0.01598	0.00042	1.648	479	0.1001	ns

SD, standard deviation; Diff, hypothesized mean difference; df, degree of freedom; p, probability value; ns, not significant at 0.05. N=480.

values was explained by Stump diameter in the 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 Adj.R^2, SEE, PRESS and AIC which are standard ways of verifying models predictive ability as pointed out by Li et al. (2002), Huang et al. (2003) and Shamaki and Akindele (2013).

Based on the model evaluation result, the power model (B4) was selected out of the six candidate models. Model B4 had the least values of; SEE, PRESS and AIC with a high Adj.R^2. This result was similar to report of Tewari and Singh (2008) that developed basal area projection model for unthinned pure even-aged plantations of Eucalyptus hybrid in Gujarat State of India. Similar result was also reported by Murphy and Shelton (1996) who modeled individual-tree basal area growth for loblolly pine. 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. In the same vein, the performance of power model in this study was in no doubt justified by the theories in plant science; that many structure and functional variables of organisms (Y) scale as power functions of measures of sizes (X) such as body mass, length, diameter, area, and volume (Norberg 1988; West et al. 1999; Enquist 2002; Chen et al. 2007).

Therefore, all the evaluation criteria (Adj.R^2, SEE, PRESS and AIC) were considered in the selection of the models. The higher the Adjusted R^2 value the better the model, also the lower the SEE, PRESS and AIC the better the model. The efficiency of this procedure was confirmed by Akindele (1985) and Odunlami (1992). 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 a non-significant difference. This indicates that the developed BA-Ds model (B4) was valid for estimating basal area of *T. grandis* stands in the study area.

Conclusion

Predicting tree growth characteristics from stump diameter can aid the reconstruction of sizes of removed trees. These includes; reviewing harvesting practices, assessing damage due to catastrophic events, creating historical records of past management activities, and establishing loss due to timber trespass. Hence, stump diameter was therefore, used as the only independent variable owing to its strong positive correlation with Dbh as asserted by this study. Thus, both Dbh and Ds can be used interchangeably.

This study concludes that, individual tree basal area can be estimated from stump diameter using the power function (Model B4) in an event of indiscriminate and/or illegal felling in Omo Forest Reserve, Nigeria. Furthermore, inclusion of other stump variables (stump basal area and stump height) as independent variables is recommended for further study. Hence, stump diameter should be taken at several points above and below 0.3 m.

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