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

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Abstract

Illegal exploitation of timber species in developing countries have increased over the years. Though, there is dearth of empirical models for describing the dimension, structure, quality and estimating quantity of a removed tree needed for assessment of damage due to catastrophic events, creating historical records of previous management activities and for conviction of illegal loggers. The objective of this study was to develop and test non-linear models that can effectively estimate individual tree merchantable height (Ht) from stump diameter (Ds) for *Tectona grandis* stands in Omo Forest Reserve, Nigeria, for timber valuation in case of illegal felling. Thirty-six temporary sample plots (TSPs) of size 25x25 m were laid randomly in six age strata of *T. grandis*; 26, 23, 22, 16, 14, and 12 years specifically. Diameter at breast height, Ht and Ds were measured for all living *T. grandis* trees within the 36 TSPs. Least square method was used to convert the counted stumps into harvested stem height. Four Ht-Ds models were fitted and evaluated. The Ht-Ds relationship was best described by square model which gave least values of root mean square error (0.083) and Akaike information criterion (-7578). This study revealed that height estimation was realistic even when the only information available was stump diameter. The square model was validated using independent data not used in the model calibration and was found to be appropriate for estimating the height of *T. grandis* stands in Omo Forest Reserve, Nigeria.

Keywords: Tree height, Non-linear model, Stump diameter, Square, Tectona grandis

1. Introduction

One of the major problem facing tropical forests in developing countries is illegal logging. Nevertheless, Nigerian forests lands have been decreasing steadily due to the indiscriminate felling of trees and activities of illegal loggers (Emeghara, 2012; Ikuomola et al. 2016). Lack of empirical information on the dimensions of trees removed from a forest could act as impediment in the conviction of illegal loggers. However, in judicial proceedings, relevant facts are required to be backed up with quantifiable evidence (Evidence Act, 1990). According to Adebagbo (1992), a total of 298 trees comprising 19 different valuable species in the year 1990 were illegally extracted from Supoba Forestry Reserve in Edo State of Nigeria but log dimensions were unknown.

The relationship between tree height and stem diameter is one of the most important components of forest structure and growth and yield models (Soares and Tome, 2002). Estimations of timber volume, site index, succession, carbon sequestration (Spurr, 1952; Botkin et al., 1972; Kurz et al., 1992; Vanclay, 1994; Peng et al., 2001), as well as stand description and damage appraisals (Parresol, 1992; Zhang, 1997) are highly related to the tree height-diameter relationship.

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However, tree height measurement is difficult and tedious task in forest inventory. The occurrence of visual obstacles, much time requirement and the chance of observer error and are among the main difficulties in measuring tree height (Colbert et al., 2002; Krisnawati et al., 2010) especially in dense forest. By contrast, tree variables such as diameter at breast height (Dbh) and stump diameter (Ds) are easy to measure with simple instruments, little investment of time and cost and with a high level of accuracy. Hence, stem diameters are good predictors of height (Lumbres et al., 2011; Ahmadi, 2013).

Consequently, numerous reasons could necessitate the reconstruction of height and/or size of removed trees. These reasons include; describing the structure of a removed tree, creating historical records of past management activities, reviewing harvesting practices, assessing damage due to catastrophic events 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).

Previous studies (Osho, 1983; Westfall, 2010; Özçelík et al., 2010; Shamaki and Akindele, 2013) have been able to estimate volume of removed trees from stump diameter. However, volume of a tree alone might not be enough in describing a removed tree, especially in judicial proceedings. Hence, information about other growth characteristic of a removed tree such as height is required to ascertain claims and aid successful establishment and description of value of the tree loss. Furthermore, in some situation, tree heights can be more valuable than its volume, for instance, in a plantation established for pole rather than timber. The ability to develop models that can easily and accurately estimate tree height 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), especially in the case of illegal logging.

However, this study aimed at developing models for estimating merchantable height from stump diameter of *T. grandis* plantations in Omo Forest Reserve, Nigeria, which will serve as tool in estimation of timber lost, descriptive evidence for a removed tree vertical length in litigation process as well as creating historical records of past management activities of the forest reserve.

2. Materials and Methods

2.1 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 6º 35′ to 7º 05′ N and Longitudes 4º 9′ to 4º 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).

2.2 Data collection

Data used for this study was collected from 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 in 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 25x25 m size in the stands (six plots per age stratum). Within each sample plot, the following tree growth variables were measured: merchantable height (m), stump diameter and diameter (cm) outside bark at breast height (i.e. Ds and Dbh measured at 0.3 m and 1.3 m above the ground level, respectively), A total number of one thousand nine hundred and nineteen (1, 919) trees were measured in all the thirty six randomly selected sample plots.

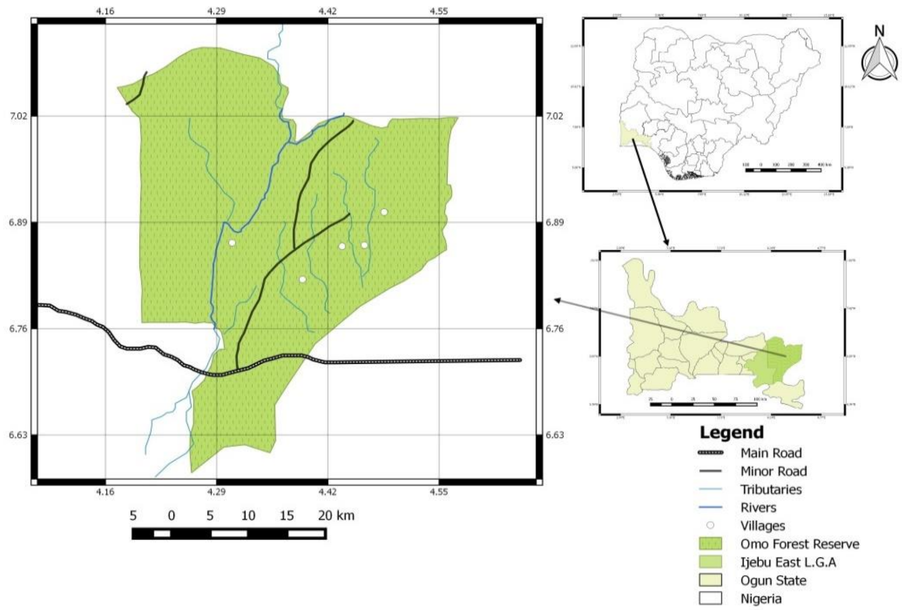

Figure 1: Map of Omo Forest Reserve, Nigeria

3. Data Analysis

3.1 Model description and fitting procedure

The available fitting data consists of measurements taken from trees located within different selected plots. In this study, least square method was used to fit data using the four candidate (nonlinear) functions (equations 1-4).The Height-Stump diameter models developed and tested in this study were the Square, Hyperbolic, Modified Logistic and Exponential models. The tree Height-Stump diameter model formulated to express tree height (merchantable) as a function of stem diameter (stump). The models are in the following forms:

$$Ht = b_0 + b_1\left(\frac{1}{Ds}\right)^2$$ (Finger, 1992; Navroodi et al., 2016) (1)

$$Ht = 0.3 + \frac{Ds^2}{(b_0 + b_1 Ds + b_2 Ds^2)}$$ (Loetsch et al., 1973) (2)

$$Ht = 0.3 + \frac{b_0}{(1 + {b_1}^{-1}.Ds^{-b_2})}$$ (Huang et al., 1992; Ahmadi 2013) (3)

$$Ht = 0.3 + b_0.e^{\left(\frac{b_1}{Ds + b_2}\right)}$$ (Ratkowsky, 1990; Ahmadi, 2013) (4)

Where:

Ht = Merchantable height (m)

Ds = Stump diameter

b_0, b_1 and b_2 = regression parameters

e= exponential

3.2 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), Akaike information criterion (AIC) and highest adjusted coefficient of determination (Adj.R^2) was selected as best. They are mathematically expressed as follows:

$$Adj.R^2 = 1 - \frac{(1-R^2)(n-1)}{n-p} \quad (5)$$

$$RMSE = \sqrt{\frac{\Sigma(Y_i - \hat{Y}_i)^2}{n}} \quad (6)$$

$$AIC = n\ln(RSS/n) + 2p \quad (7)$$

Where:

$\bar{Y}_i$ = arithmetic mean of the observed value

Y_i = observed value of Y for observation i

$\hat{Y}_i$= predicted value i

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

ln = natural logarithm.

In addition, residual plots were carried out to check the error assumption. The significance of the parameter estimates was also observed. The overall best candidate model was validated using an independent data set of about 25% (392 trees) of the total data (1,919 trees) collected for this study. The t-test for paired samples was adopted as model validation method; a confidence level of $p<0.05$ was used for statistical significance.

4. Results

4.1 Data summary

The model fitting data set covered a wide range. The mean, maximum and minimum of the measured variables are presented in the box and whiskers plot (Figure 2 and 3). The distribution of stump diameter (Ds) ranged from 7.67 to 48.97cm and Ht ranged from 3.7 to 18.9 m^2. The mean values and standard error (SE) of stump diameter and merchantable height were displayed in the box plots (Figure 2 and 3). The result of Pearson's product-moment correlation analysis between Ht, Ds and Dbh (Table 1) revealed that Ds is highly and positively correlated with Dbh (r=0.96). The result also shows that Ht is positively correlated with Ds with r value of 0.50. The graphical relation between the explanatory variable (Ds) versus response variable (Ht) was displayed in Figure 4. The scatter plot (graph) showed a curve-linearly relationship between merchantable height and stump diameter of *T. grandis* in the study area.

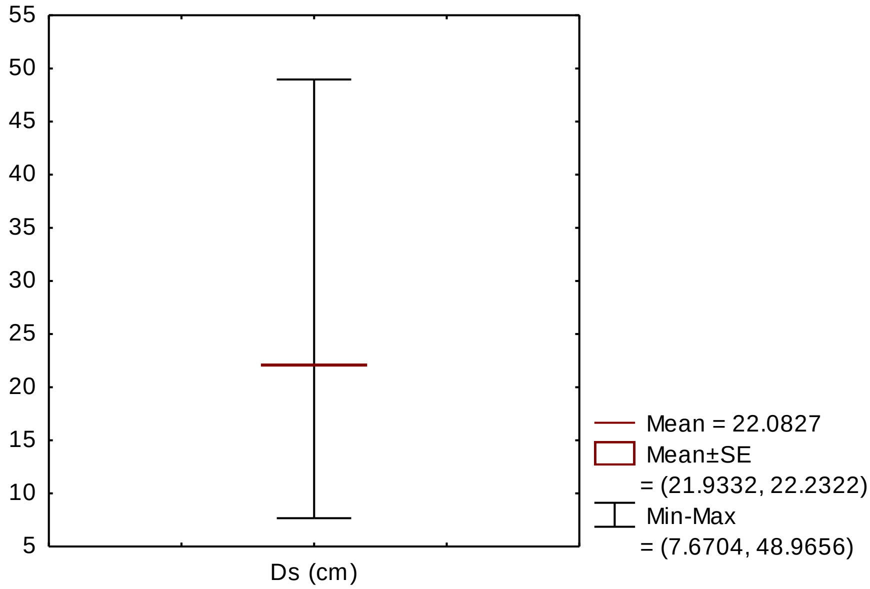

Figure 2: Box and whisker summary statistics of tree stump diameter (Ds) in cm.

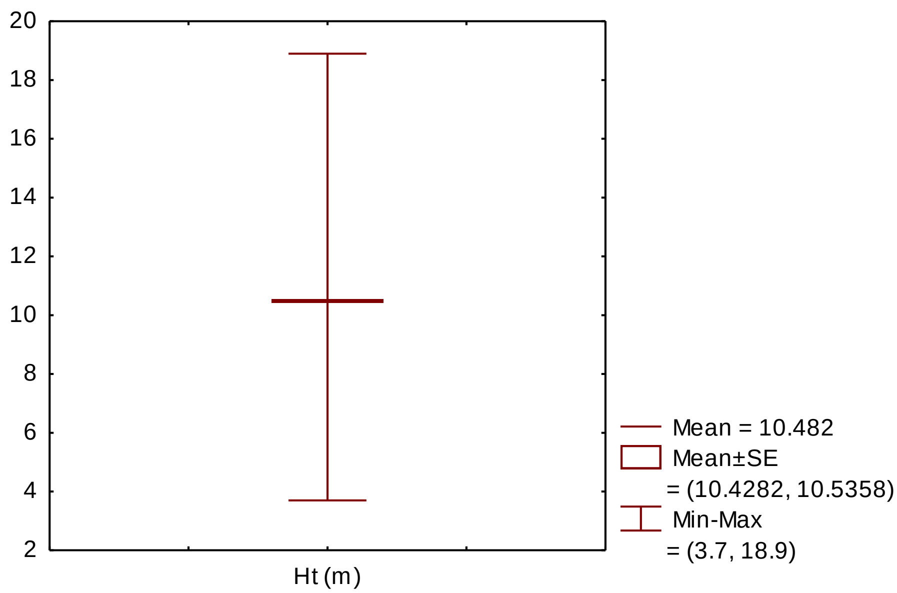

Figure 3: Box and whisker summary statistics of tree merchantable height (Ht) in m.

Table 1: Correlation matrix of tree growth variables.

	Ds	Dbh	Ht
Ds	1		
Dbh	0.96*	1	
Ht	0.50*	0.52*	1

* Correlation coefficient is significant at the 0.05 level (2-tailed), Merchantable height (m), Dbh=Diameter at breast height (cm) and Ds=Stump diameter (cm). Number of tree=1919

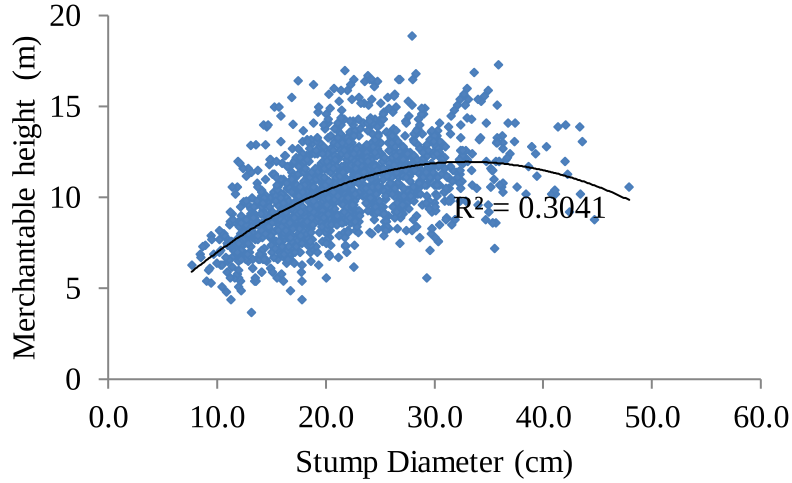

Figure 4: Relationship between merchantable height and stump diameter.

4.2 Height-Stump diameter models

The models developed in this study was to estimate the present and future values of merchantable height at individual tree level for *T. grandis* stands in Omo Forest Reserve, Nigeria. The models were developed using individual tree merchantable height as dependent variable and stump diameter as independent variable. All parameters were found to be significant at the 5% level of probability.

Out of the four models fitted using Ds as independent variable; the Square function gave the least values of RMSE (0.083) and AIC (-7578.5) and the highest Adj. R^2 (0.314). However, the Exponential function gave the highest values RMSE (2.045) and AIC (2,191.01) and least Adj.R^2 (0.224). Figure 5 showed the graph of the residuals distribution against the predicted of height.

4.3 Model validation

Thevalidation test result shows that observed value was not significantly different from the predicted value of the predicted at probability level of 0.05 (Table 3).

Table 2: Examined Height-Stump Diameter Models.

Functions	Parameters			Fit Statistics		
	b_0	b_1	b_2	Adj.R^2	RMSE	AIC
Square	1.087	-29.393		0.314	0.083	-7578.5
Hyperbolic	1	-0.982	0.936	0.300	1.942	2033.37
Modified Logistic	0.000005	0.000002	-0.392	0.273	1.979	2091.64
Exponential	0.029	-2231.3	-403.04	0.224	2.045	2191.01

Where:

b_0, b_1, b_2 = regression parameters
Adj.R^2 = adjusted coefficient of determination
RMSE= root mean square error
AIC= Akaike information criterion

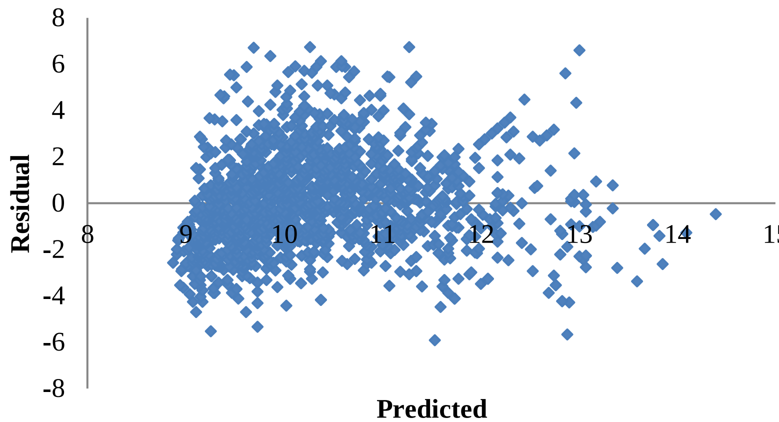

Figure 5: Residual distribution against Ht using square model.

Table 3: Results of validation of square model using t test for paired sample.

Function	Mean Obs.	Mean Pred.	t-value	δ^2 Obs.	δ^2 Pred.	p-value	df	Remark
Square	94.87	94.81	1.648	265.68	263.98	0.376	391	ns

Where:

δ2 = variance,
df= degree of freedom,
Ht = merchantable height (m),
ns = not significant (P>0.05). Numbers of tree = 392

5. Discussion

This study provided information on the stem diameter (Ds and Dbh) and merchantable height (Ht) of *Tectona grandis* stands in Omo Forest Reserve (Table 1 and Figure 1-2). This study however, concerted effort towards estimating merchantable height at individual tree basis using stump diameter. A high positive bivariate correlation was observed between stump diameter and diameter at breast height. This implies that Dbh increase with the increase in stump diameter. This result is similar to the reports of Oyebade and Onyambo, (2011), Shamaki and Akindele (2013) and Chukwu et al. (2017) 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. Osho (1983), Westfall (2010), Özçelík et al. (2010), Shamaki and Akindele, (2013) and Chukwu et al. (2017) upheld this method stating that,estimating tree growth variables after exploitation can only be possibly done through the stumps diameter, as tree stump is possibly the only tree part left after logging.

The nonlinear Ht-Ds models fitted in this study were in square, hyperbolic, modified logistic and exponential functions form (Equations 1-4, respectively). All parameters were found to be significant at the 5% level of probability. The criteria adopted for selecting the best model was through comparison of

Adj.R^2, RMSE and AIC which are standard ways of verifying models predictive ability as pointed out by Huang et al. (2003), Shamaki and Akindele (2013) and Navroodi et al. (2016).

Consequently, this study considered Adj.R^2, RMSE and AIC as evaluation criteria in the selection of models. The higher the Adjusted R^2 value the better the model, also the lower the RMSE and AIC the better the model. The efficiency of this procedure was confirmed by Navroodi et al. (2016) and Chukwu et al. (2017). Based on the model evaluation results, the square model was selected out of the four non-linear candidate models. The Square model had the least values of; RMSEand AIC with the highest Adj.R^2. This result was similar to the reports of Oyebade and Onyambo (2011) that used nonlinear technique to develop Height-Diameter predictive equations for Rubber (*Hevea brasilliensis*) plantation in Choba, Port-Harcourt, Nigeria. However, the Height-Stump diameter models developed in this study showed low Adj.R^2 and high RMSE except for the square function. This may be as a result of the large numbers of tree (1,527) used in this study as compared the 144 trees used by Oyebade and Onyambo (2011). However, Okojie (1985) stated that, Height–Diameter equations are usually constructed from few samples. Furthermore, Popoola and Adesoye (2012) and Shamaki (2016) reported similar and/or low coefficients of determination (R^2) for nonlinear model and selected the best model based on low error terms.

In the graphical relationship between the residuals and estimated merchantable height obtained with the square function, displayed constant error variance was distributed on both in the positive and negative region of the x-axis (i.e. the estimated height values). This is desirable for a good model. This trend was similar to the findings of Sánchez et al. (2003) and Oyebade and Onyambo (2011).

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 merchantable height. The result showed a non-significant difference. This indicates that the developed Ht-Ds model (Square) was valid for estimating height of *T. grandis* stands in the study area.

6. Conclusion

This study revealed that tree growth characteristics can be estimated from stump diameter. Hence, aid in the reconstruction of sizes of removed trees, which includes; describing the structure of a removed tree, creating historical records of past management activities, reviewing harvesting practices, assessing damage due to catastrophic events and establishing loss due to indiscriminate and/or illegal felling.

This study concludes that, individual tree merchantable can be estimated from stump diameter using the square function 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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