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Original Article

Models for estimating crown projection area from stump diameter for *Tectona grandis* Linn. f. in the tropical rainforests of Nigeria

Nijerya'nın tropikal yağmur ormanlarında *Tectona grandis* Linn ağacı tepe tacı izdüşüm alanının kütük çapı ile tahmin modelleri

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ABSTRACT

The estimation of growth variables for a cleared tree is crucial in forest management. Most importantly, growth variable estimation for cleared trees allows for the conviction of illegal loggers in judicial proceedings and biomass estimation. Hence, the present study developed empirical models that are capable of precisely estimating the crown projection area (CPA) of trees from tree's stump diameter (Ds) to serve as a crucial tool for evaluating tree loss and as descriptive evidence to inform the litigation process. The data for this study were gathered from 36 randomly laid 25 m×25 m temporal sample plots within six stand ages of *Tectona grandis* within a Nigerian reserved tropical rainforest. Least squares method was used to fit six regression models, namely simple linear, power, single logarithmic, growth, reciprocal, and square functions. The power model estimated CPA from Ds most appropriately by employing the lowest values of the root mean square error (8.42 m^2), Akaike information criterion (6514.13), and Bayesian information criterion (6524.79). Furthermore, t-test result yielded a non-significant (p=0.431) difference between the observed and predicted CPA utilizing the power model. Hence, the power model was recommended for the conversion of counted stumps into harvested trees' CPAs.

Keywords: Regression models, stump, timber trespass, tree crown, tropical rainforest

ÖZ

Bir ağaç için büyüme değişkenlerinin tahmini orman yönetiminde çok önemlidir. Ağaç büyüme değişkenleri için en önemli tahmin ağaçlar için büyüme değişken tahmini olup, bu tahmin biyokütle hesaplamalarında yasadışı odun üreticilerinin varlığının ispatlanmasına yardımcı olabilir. Bu nedenle, bu çalışma ile, odun üretimi kaybının belirlenmesi için önemli bir araç oluşturmak ve yasa dışı odun üreticileriyle ilgili, hukuki sürecin bilgilendirilebilmesi amacıyla açıklayıcı bir kanıt oluşturmak için ağaçların kütük çapından (Ds) ağaçların tepe tacı izdüşüm alanını (CPA) tam olarak tahmin edebilen ampirik modeller geliştirilmeye çalışılmıştır. Bu çalışma için gerekli veriler, Nijerya'da bir tropik yağmur ormanı içinde *Tectona grandis* ağacının bulunduğu altı farklı meşçere yaşına sahip, rastgele seçilmiş 25 m × 25 m ölçülerindeki 36 adet örnekleme alanından toplanmıştır. En küçük kareler yöntemi, basit doğrusal, güç, tek logaritmik, büyüme, karşılıklı ve kare fonksiyonları olmak üzere toplam altı regresyon modeline uyacak şekilde kullanılmıştır. Güç modeli, kök ortalama kareleri hatasının (8,42 m^2), Akaike bilgi kriteri (6514,13) ve Bayes çıkarımı kriterinin (6524,79) en düşük değerleri kullanılarak kütük çaplarından (Ds), tepe tacı izdüşüm alanı (CPA) en uygun şekilde tahmin edilmeye çalışılmıştır. Ayrıca, t-testi sonucu, güç modeli kullanılarak gözlemlenen ve tahmin edilen tepe tacı izdüşüm alanı (CPA) arasında anlamlı olmayan (p=0,431) bir fark verdiği görülmüştür. Bu nedenle, izinsiz kesilmiş ağaçlara ait kütüklerin sayısıyla, hasat edilen ağaçların tepe tacı izdüşüm (CPA) alanlarına dönüştürülmesi için güç modeli önerilmiştir.

Anahtar Kelimeler: Regresyon modelleri, kütük, izinsiz ağaç kesilmesi, ağaç tepe tacı, tropikal yağmur ormanı

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INTRODUCTION

Tropical rainforests comprise one of the world's major vegetation types (Whitmore, 1998). Tropical rainforest consist of the most biodiversity of all terrestrial ecosystems, home to more plant and animal species than any other biome (Akindele and LeMay, 2006; Turner, 2001). The FAO (1999) estimated an annual loss of 127,300 km^2 of the world's tropical forest. This loss was attributed to indiscriminate and/or illegal logging activities and overexploitation of trees (Akindele and LeMay, 2006). Hence, the availability of empirical information ascertaining the dimensions of trees removed from a forest is capable of facilitating the conviction of illegal loggers. However, supporting evidence with relevant and empirical facts is of high importance within judicial proceedings (Evidence Act, 1990). Hence, estimating the dimensions of a removed tree is possible via its stump diameter (Osho, 1983; Özçelík et al., 2010).

Various reasons could support the reconstruction of the growth characteristics and dimensions of cleared. Several of these reasons may include: establishing biomass loss due to indiscriminate and/or illegal felling, reviewing harvesting practices, and/or assessing damage due to catastrophic events (Corral-Rivas et al., 2007). Studies (Osho, 1983; Özçelík et al., 2010) have demonstrated that tree stump diameter can be utilized in place of diameter at breast height while estimating the majority of tree growth variables, especially in regards to illegal logging, due to their positive, high, and significant correlation. Özdemir et al. (2020) determined the relationship between the stump diameter and diameter at breast height for sessile oak (*Quercus petraea* (Matt.) Liebl) stands in the Northern Marmara Region. Manyanda et al. (2019) also developed biomass and volume models based upon stump diameter for purposes of assessing the degradation of Miombo Woodlands in Tanzania. The aboveground component of estimated biomass included the crown which anchors branches and tops.

The tree crown comprises the site where physiological activities which drive the growth and development of a tree occurs (Leites and Robinson, 2004). The crown is also the part of the tree that displays the first signs of deterioration. Hence, the crown of trees can be utilized as an indicator for a tree's health. Dubravac et al. (2009) stated that the tree crown comprises one of the most crucial elements of tree and forest structure. Prior studies have been able to estimate diameter at breast height (Osho, 1983), volume (Shamaki and Akindele, 2013), height (Chukwu and Osho, 2017) and basal area (Chukwu and Osho, 2018) from the stump diameter of *Tectona grandis* Linn. f. species within the tropical rainforest of Nigeria. However, these tree growth variables alone may not be sufficient in describing and further evaluating a cleared tree, particularly within judicial proceedings and biomass estimation.

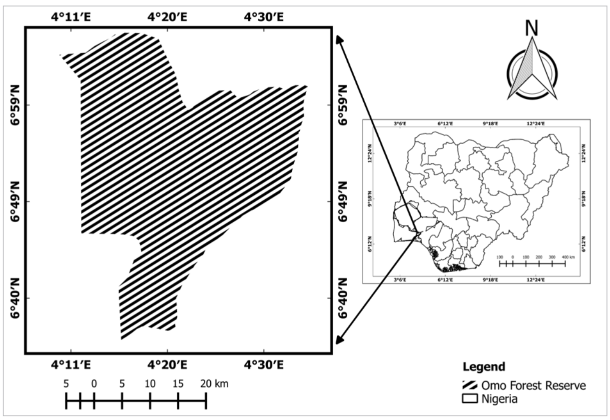

Figure 1. Map of Omo Forest Reserve, Nigeria

Hence, the present study aimed to develop an empirical model that can precisely estimate tree crown projection (CPA) area from stump diameter in order to serve as a tool for evaluating tree loss, providing descriptive evidence in a litigation process, and facilitating input variable biomass estimation.

MATERIALS AND METHODS

Data

The present study occurred in temporary sample plots (TSPs) of *Tectona grandis* stands of differing age series: 26, 23, 22, 16, 14, and 12 years, located within Omo Forest Reserve, within the tropical rainforest of Nigeria. The reserve lies between latitude 6° 3′–7° 5′ N and longitudes 4° 9′–4° 40′ E (Figure 1), comprising a total land area of 139,100 ha, with a mean annual rainfall of 1,200 mm and average elevation of approximately 91 m above sea level. A stratified random sampling technique was utilized in the present study. The six age series of *Tectona grandis* stands present within the plantation constituted the strata within the study area. Following this, a simple random sampling technique was employed in the allocation of six (6) TSPs of 25 m×25 m (0.0625 ha) size in each of the six (6) age stratum, comprising a total of thirty-six (36) plots. An aggregate number of one thousand nine hundred and nineteen (1919) trees were measured across all the thirty-six randomly selected sample plots. Tree growth variables measured include: stem diameter outside bark at stump and breast height (0.3 m and 1.3 m above the ground level, respectively), alongside crown diameter.

The tree crown diameter measurements were based upon the assumption that the vertical projection of a tree crown is circular. Four radii were measured in the direction forming equal angles (Krajicek et al., 1961, Chukwu et al., 2017). Tree crown diameter was measured via projecting the diameter of the crown with ranging poles upon the ground adjusted in four different directions and taking the distance between the ranging poles utilizing measuring tape calibrated in meters. The crown diameter was then obtained by taking the average of the two readings recorded from the four directions for each tree. Crown diameter (CD) was then calculated as such:

$$CD = \sum \frac{r_i}{2} \quad (1)$$

Where,
CD= average crown diameter,
r_i=projected crown radii measured on four axis.

Table 1. Models examined for predicting crown projection area from stump diameter

Model Code	Function form	Designation	Equation number
C1	$CPA = b_0 + b_1 Ds$	Simple linear	(3)
C2	$CPA = b_0 Ds^{b_1}$	Power	(4)
C3	$CPA = b_0 + b_1 \ln Ds$	Single logarithm	(5)
C4	$CPA = e^{b_0 + b_1 Ds}$	Growth	(6)
C5	$CPA = b_0 + b_1 \frac{1}{Ds} + b_2 \frac{1}{Ds^2}$	Reciprocal	(7)
C6	$CPA = b_1 Ds^2$	Square	(8)

CPA: crown projection area (m^2); Ds: stump diameter (cm); b_0, b_1 and b_2: regression parameters; e: exponential; ln: natural logarithm

Table 2. Descriptive statistics of tree growth variables

			Descriptive Statistics			
Data	Variables	N	Minimum	Maximum	Mean	SD
Modeling	Ds (cm)	1527	16.4	49.0	22.1	6.45
	Dbh (cm)	1527	10.0	37.9	17.8	5.31
	CD (m)	1527	2.2	11.0	5.8	1.21
	CPA (m^2)	1527	3.8	94.2	27.4	11.67
Validation	Ds (cm)	392	17.7	47.9	22.8	6.89
	Dbh (cm)	392	10.2	38.9	18.5	5.62
	CD (m)	392	3.1	9.0	5.7	1.15
	CPA (m^2)	392	7.3	64.1	27.1	10.77

SD: standard deviation; Ds: stump diameter; CD: crown diameter; CPA: crown projection area; Dbh: diameter at breast height; N: number of trees. Total number of trees measured=1919

Furthermore, CPA was computed from CD as:

$$CPA = \frac{\pi(CD^2)}{4} \quad (2)$$

Where: CPA=crown projection area (m^2), CD=crown diameter (m) and π =Pi is constant (3.142)

Data Analysis

Descriptive statistics were then performed for the tree variables gathered in the field. Data (1919 trees) was divided into two sections; with approximately 80% (1527 trees) for model fitting and 20% (392 trees) for model validation. Pearson's product-moment correlation was utilized in order to examine the linear associations among the variables used.

The least squares method was employed to fit the data to six candidate functions (equations 3-8). The level of significance of the parameters was assessed based upon the Wald test, utilizing SPSS Statistics 20.0 software (SPSS Inc., IBM, Chicago, USA). The models were formulated and tested in order to express tree CPA as a function of its stump diameter (Table 1).

The models developed for the purposes of the present study were evaluated based upon the graphical and numerical analysis of the residuals which are: model with lowest values of the root mean square error (RMSE), Akaike information criterion (AIC), and Bayesian information criterion (BIC) was selected as best. They are mathematically expressed as:

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

$$AIC = n\ln\left(\frac{RSS}{n}\right) + 2p \quad (10)$$

$$BIC = \ln(n)p + n\ln\left(\frac{RSS}{n}\right) \quad (11)$$

Where; Y_i =observed value of Y for observation *i*, $\hat{Y}_i$ =predicted value, *in*=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.

Additionally, the error assumption was checked using residual plots. The significance of the parameter estimates was also observed. The model that was selected as the best among the six candidate models was validated utilizing an independent data set of approximately 20% (392 trees) of the total data (1919 trees) gathered for this study. Furthermore, a t-test for paired samples was adopted as the model validation method; a probability level of $p<0.05$ was employed for statistical significance. The present study employed SPSS Statistics 20.0 software (SPSS Inc., IBM, Chicago, USA) for all statistical analysis.

Table 3. The parameter estimates of candidate models coefficients and fit statistics

	Parameter			Fit Statistic		
Model Code	b_0	b_1	b_2	RMSE (m^2)	AIC	BIC
C1	0.096	1.25		8.43	6514.16	6524.82
C2	1.239	1.004		8.42	6514.13	6524.79
C3	−51.58	25.984		8.61	6580.39	6591.06
C4	2.399	0.04		8.51	6544.13	6554.80
C5	73.371	−1321	7312.04	8.59	6572.25	6588.24
C6		2.991		8.90	6678.98	6684.31

RMSE: root mean square error; AIC: Akaike information criterion; BIC: Bayesian information criterion (BIC); b_0, b_1 and b_2: parameters estimates. Numbers of tree used for modeling=1527. Significance level regarding t value of parameters was p<0.05.

Table 4. Paired sample t-test results of validation of Power Model (C2)

Model code	Mean Obs.	Mean Pred.	t- value	δ^2 Obs.	δ^2 Pred.	p- value	df	Remark
C2	27.11	27.41	1.710	115.97	68.69	0.431	391	ns

δ^2: variance; df: degree of freedom; ns: not significant (p>0.05). Total number of trees for model validation=392.

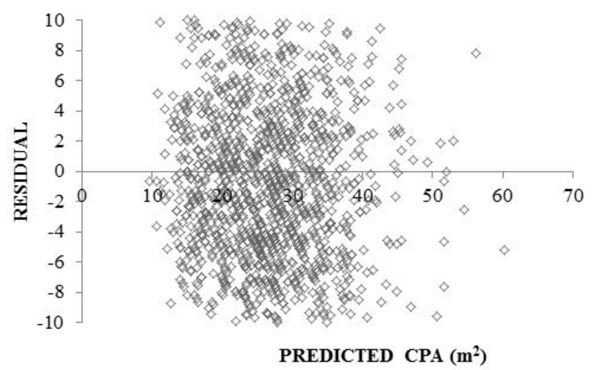

Figure 2. Residual distribution against predicted CPA using power model

RESULTS AND DISCUSSION

Results

The result of the descriptive statistics for the tree growth variables utilized for modeling revealed that the distribution of stump diameter (Ds) ranged from 16.4 to 49.0 cm, the diameter at breast height (Dbh) ranged from 10.0 to 37.9 cm, the CD ranged from 2.2 m to 11.0 m, and crown projection area (CPA) ranged from 3.8 m^2 to 94.2 m^2 (Table 2). In a similar vein, the descriptive statistics results for the validation data demonstrated that the distribution of Ds ranged from 17.7 to 47.9 cm, Dbh ranged from 10.2 to 38.9 cm, CD ranged from 3.1 m to 9.0 m, and CPA ranged from 7.3 m^2 to 64.1 m^2 (Table 2). The corresponding mean and standard deviations for the growth variables were in addition presented in Table 2.

The result of Pearson correlation for tree growth variables indicated that the stump diameter possessed significant, positive, and high correlation with the diameter at breast height (r=0.96), the CD (r=0.71), and the CPA (r=0.70).

The fitting of CPA-Ds models utilizing least squares regression demonstrated that all of the parameters in models were significant (p<0.05). The estimated parameters of the six model functions for *Tectona grandis* were displayed in Tables 3. In addition, Table 3 presented fit statistics for the candidate models examined within the present study. The results of goodness of fit for the models showed that Model C2 (Power) possessed the lowest values of RMSE (8.42 m^2), AIC (6514.13), and BIC (6524.79), followed by Models: C1, C4, C5, and C3 (simple linear, growth, reciprocal and single logarithmic functions, respectively). However, the square function (Model C6) possessed the highest values of RMSE (8.90 m^2), AIC (6678.98), and BIC (6684.31).

Figure 2 displayed the graph of the residuals distribution against the predicted CPA. Thus, the power model (C2) demonstrated that the residual is distributed ±11 m^2.

The model validation result for the selected model possessing the best performance based upon the fit statistics considered within the present study was presented in Table 4. The validation test demonstrates that the observed value for CPA estimated using Model C2 was not significantly different (p=0.431) from the predicted value of CPA at a probability level of 0.05.

Discussion

Information regarding the tree growth variables (Ds, Dbh, CD, and CPA) employed in the present study was displayed (Table 1). According to Palmer and Synnott (1992), information regarding the forest stand is essential in order to achieve sustainability within forest management. However, the reduction of the stem diameter from the base toward the top of the tree as displayed within Table 1 confirms the biological validity of the data set as highlighted by Husch et al. (2003). The correlation between crown dimensions and tree stem diameter were high and positive, which implies that the CD and the projection area increases with the increase in Dbh and stump diameter. However, our study's efforts were concentrated toward estimating individual tree CPA from the stump diameter. A high, positive, and significant correlation was observed between the tree diameter at breast height and the stump diameter. Hence, this infers that Dbh increase with the rise in stump diameter. Similar results were reported by Shamaki and Akindele (2013) and Chukwu et al. (2017).

However, to avoid co-linearity between the diameter at breast height and the stump diameter, only the stump diameter was selected as an independent variable for developing models in the present study as indicated by Huang et al. (2003). The principle of utilizing solely stump diameter was to aid forest managers in obtaining information on the original structure of a tree/forest following exploitation either by legal or illegal activities within the forest itself. Previous studies (Chukwu et al., 2017; Chukwu and Osho, 2017; Özçelík et al., 2010) upheld this method, stating that estimating tree growth variables following exploitation is only possible of being performed via the stump's diameter, as the tree stump is possibly the only part of a tree left after logging.

The model forms investigated within the present study are simple linear, single logarithmic, growth, reciprocal, and square functions (Models C1-C6, respectively). All parameters for the six models developed were found to be significant at the 95% level of probability. RMSE, AIC, and BIC were adopted as measures for goodness of fit. These measures comprise standard methods of verifying models predictive ability as pointed out by Adesoye and Ezenwenyi (2014), Chukwu and Osho (2017), and Chukwu et al. (2017).

Model C2 (power) possessed the lowest values of RMSE, AIC, and BIC. Accordingly, it was selected as the best out of the six models evaluated, owing to its distinct precision and parsimonious characteristics. This result was in agreement with the findings of Shimano (1997), who observed that tree crown projection area-stem diameter relationships can be best described by power models. The result of our study was also comparable to the reports of Avsar and Ayyildiz (2005), who observed that crown diameter-Dbh relationships can be best described by power models. However, their previous report covered CD and Dbh, which are surrogates to CPA and stump diameter, respectively (Adesoye and Ezenwenyi, 2014; Özçelík et al., 2010).

Nevertheless, the graph of the residual against the predicted CPA for the power model (C2) demonstrated that the homoscedasticity assumption was upheld. This is desirable for a coherent model. This trend was similar to the findings of Shimano (1997) and Avsar and Ayyildiz (2005). Likewise, the result of the paired t-test employed for the further validation of the selected model revealed that Model C2 was adequate for estimating the CPA of *Tectona grandis* from the stump diameter. The result demonstrated a non-significant difference (p=0.431) between the predicted and the observed CPA.

CONCLUSION

Tree stump diameter was utilized as the singular independent variable in order to estimate the CPA. This will aid in the reconstruction of the sizes of a cleared tree's crown and/or creating historical records of past management activities, reviewing harvesting practices, assessing tree damage due to catastrophic events, establishing loss due to timber trespass, and further estimation of biomass. This study further concluded that the power function (Model C2) can precisely estimate the CPA from stump diameter for *Tectona grandis* data. Hence, the present study recommends that further research should consider measuring stump diameter at several points above and below 0.3 m, this may improve the predictive ability of the model.

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