

**Evaluating Crown-Diameter Prediction Models for *Terminalia superba* (Engl. & Diels) in Onigambari Forest Reserve, Nigeria**

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**ABSTRACT**

The study evaluates five dbh-crown diameter prediction models for naturally grown *Terminalia superba* (Engl. & Diels). Five models for predicting crown diameter using diameter at breast height were tested for the species in Onigambari forest reserve, Nigeria. Data were obtained from all available *T. superba* tree species (dbh  $\geq$  10cm) measured on eight 25m x 25m temporary sample plots established using systematic line transects sampling technique. One linear and four non-linear functions were selected as candidate functions to model the relationship. Regression analysis result showed that there were statistically significant ( $P > 0.05$ ) and strong ( $R^2 > 0.50$ ) relationship between dbh and crown diameter variables for all the models used. The results of the study showed that 71/ha stands of the species were available presently in the study area with mean dbh and crown diameter of 48.50 cm and 15.60m respectively. The dbh – crown diameter relationship was best described by Cubic model ( $cd = 3.724 - 0.190D + 0.035D^2 - 0.005D^3$ ,  $R^2 = 93\%$ , Coefficient of variation =  $-6.44 \times 10^{-16}$  and MSE = 0.011). This study showed that dbh can adequately predict the crown diameter very well. Therefore, the relationship as explained by cubic function can further be used to evaluate and estimate the stand volume and basal area in this forest.

**Keywords:** Crown diameter, diameter at breast height, *Terminalia superba*, models and Nigeria

## INTRODUCTION

Tree crown diameter is well correlated with tree bole diameter (Gering and May, 1995; Kigomo, 1980, 1991, 1998; Lockhart *et al.*, 2005; Hemery *et al.*, 2005). This relationship is particularly useful for determining stand density and stocking relationships (Dawkins, 1963; Goelz, 1996; Kigomo, 1980, 1991, 1998) and tree and stand volumes from aerial photographs (Bonnor, 1968; Gering and May, 1995). Furthermore crown diameter bears a definite relation with its bole diameter irrespective of site and age and, in some cases, irrespective of silvicultural treatments (Dawkins, 1963; Kigomo, 1998). If relationships between stem diameter and tree crown diameter are known, Basal Area (BA) and volume of trees in the forest can be estimated from stem diameters derived from crown diameters. Just as a tree's diameter at breast height (dbh) is often used as a surrogate for a tree's crown dimensions (Kigomo, 1980, 1991, 1998; Lockhart *et al.*, 2005), a tree's crown diameter can equally be used as the surrogate for dbh.

Dbh and crown diameter are also important tree characteristics and an accurate prediction of tree dimensions has become prominent as analysis techniques, models, and other statistical tools to allow for the rapid evaluation of extensive volumes of data. Some parameters (e.g., diameter or age) are easy to measure with simple instruments and it is widely used for forest inventories. However, a number of studies have shown that other variables which are not so easily obtained are also good predictors of forest dynamics and they can improve the reliability of tools like growth and yield models. One of these parameters is crown diameter, which has received increasing attention as a means to estimate tree growth (Bragg, 2001). Measurement of tree crown diameter is more difficult and more time consuming than that of dbh (Avsar, 2004). Crown diameter is used in tree and crown level growth-modeling systems, where simple competition indices are not available to adequately predict recovery from competition when a competitor is removed (Vanclay, 1994). Crown diameter is also used in calculating competition indices based on crown overlap (Biging and Dobbertin, 1992; Daniels *et al.*, 1986) and predicting aboveground biomass. With recent

advances in remote sensing technology, an easier way of inventorying these resources would be measuring tree crown diameter from remotely acquired high resolution digital imagery.

Crown diameter models can be formulated from open-grown trees or from stand grown trees. Equations for predicting the dimensions of crowns in open locations consider maximum biological potential, and so are known as “maximum crown width” (MCW) equations, while those for stand-grown trees which generally have a smaller crown due to competition, are called “largest crown width” (LCW) equations (Hann, 1997). LCW models predict the actual size of tree crowns in forest stands, and have many applications including estimations of crown surface area and volume in order to assess forest health (Zarnoch *et al.*, 2004), tree-crown profiles and canopy architecture (Hann, 1999; Marshall *et al.*, 2003), forest canopy cover (Gill *et al.*, 2000) and the above ground biomass. Modeling crown diameter as a simple linear model between crown diameter and dbh is often adequate (Cañadas, 2000; Paulo *et al.*, 2002; Benítez *et al.*, 2003). Other studies suggest that these linear models can be improved with quadratic expressions of diameter (Bechtold, 2003). Non-linear models have also been used, such as the power function and the monomolecular function (Bragg, 2001; Tomé *et al.*, 2001; Avsar, 2004).

According to FAO (2013), *Terminalia superba* (Afara) is a large tree in the family Combretaceae, native to tropical western Africa. In Nigeria, it grows up to 60 m tall, with a domed or flat crown, and a trunk typically clear of branches for much of its height, buttressed at the base. The leaves are 10 cm long and 5 cm broad, and are deciduous in the dry season (November to February). The flowers are produced at the end of the dry season just before the new leaves; they are small and whitish, growing in loose spikes 10–12 cm long. The fruit is a samara with two wings. The wood is either a light ('white limba') hardwood. Used for making furniture, table tennis blades (as outer ply) and musical instruments and prized for its workability and excellent colour and finish. The most famous example of its use in guitars is when it was used by Gibson in producing their now highly sought-after Flying V and Explorer guitars in 1958. For table

tennis blades, Afara and in particular black Afara is chosen for its flexibility and it is thought to enhance top spin play (CIRAD, 2009). Therefore, its physiological growth models cannot be overemphasized.

Hence, the aim of this study is to evaluate selected crown-diameter prediction models, which are inadequate, for Nigeria rainforest naturally grown *T. superba* in Oyo State. Thus, bole diameter would then be predicted from crown diameter and the tree volume or basal area (BA) estimated.

## **MATERIALS AND METHOD**

### **Study Area**

The study was carried out in Onigambari Forest Reserve (Fig.1). It is located on latitude 7° 25' and 7° 55'N and longitude 3° 53' and 3° 9'E within the low land semi-deciduous forest belt of Nigeria and covers a land area of 17,984ha. The reserve is divided into two: natural and plantation forests. The natural forest is made up of indigenous species such as *Terminalia spp*, *Triplochiton scleroxylon*, *Irvingia garbonensis*, *Treculia africana*, among others while the plantation forest is made up of mainly exotic species such as *Gmelina arborea* and *Tectona grandis*. The topography of the study area is generally undulating, lying at altitude between 90m and 140m above sea level. The annual rainfall ranges between 1200mm to 1300mm spreading over March to November. The dry season is severe and the relative humidity is low and average annual temperature is about 26.4°C (Larinde and Olasupo, 2011).

### **Sampling Techniques and Data Collection**

Systematic line transect was used in the laying of the temporary sample plots. Two transects of 400m in length with a distance of 200m between the two parallel transects were laid (fig 2). Sample plots of 25m x 25m in size were established in alternate along each transect at 100m interval and thus summing up to 4 sample plots per 500m transect and a total of 8 sample plots in the study area.

Within each plot, dbh and Crown diameter (Cd) of all *T. superba* tree species that had dbh  $\geq$  10 cm were assessed. Two crown diameters were measured per tree, one being the horizontal diameter of the axis of the crown which passes through the centre of the plot and the second being perpendicular to the first. The

arithmetic mean crown diameter was calculated from these two field measurements. Table 1 shows the summary of the data set used.

**Data Analysis and Modelling**

Five dbh-crown diameter equations (Table 2) were used to model the dbh-crown diameter relationship. One of these models is linear and others are non-linear. Comparison of the model estimates was based on graphical and numerical analysis of the residuals and values of four statistics: least values of the mean square error (which analyses the precision of the estimates), mean of residual, coefficient of variation of residual and highest value of adjusted coefficient of determination (which reflects the part of the total variance that is explained by the model). In all statistical analyses, a confidence level of  $p < 0.05$  was used for statistical significance.

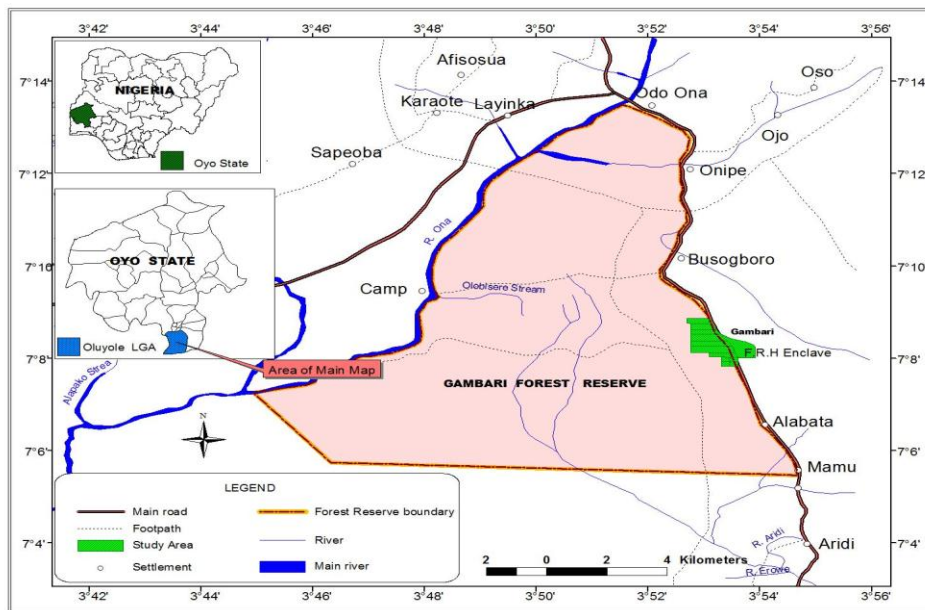


Fig 1: Map of Oniganbari forest reserve showing the study area

Table 1: Statistical summary of data set used

	Mean	Minimum	Maximum	Standard deviation	Density/ha
D (cm)	48.50	10.00	91.70	2.83	71
cd (m)	15.60	8.40	25.30	0.70	

cd = crown diameter and D = dbh

Table 2: Prediction models used

Model No	Model Name	Model
1	Linear	$cd = b_0 + b_1D$
2	Quadratic	$cd = b_0 + b_1D + b_2D^2$
3	Cubic	$cd = b_0 + b_1D + b_2D^2 + b_3D^3$
4	Exponential	$cd = b_0e^{(b_1D)}$
5	Logarithmic	$cd = b_0 + b_1 \ln D$

cd = crown diameter, D = dbh and  $b_{0...3}$  = regression constants

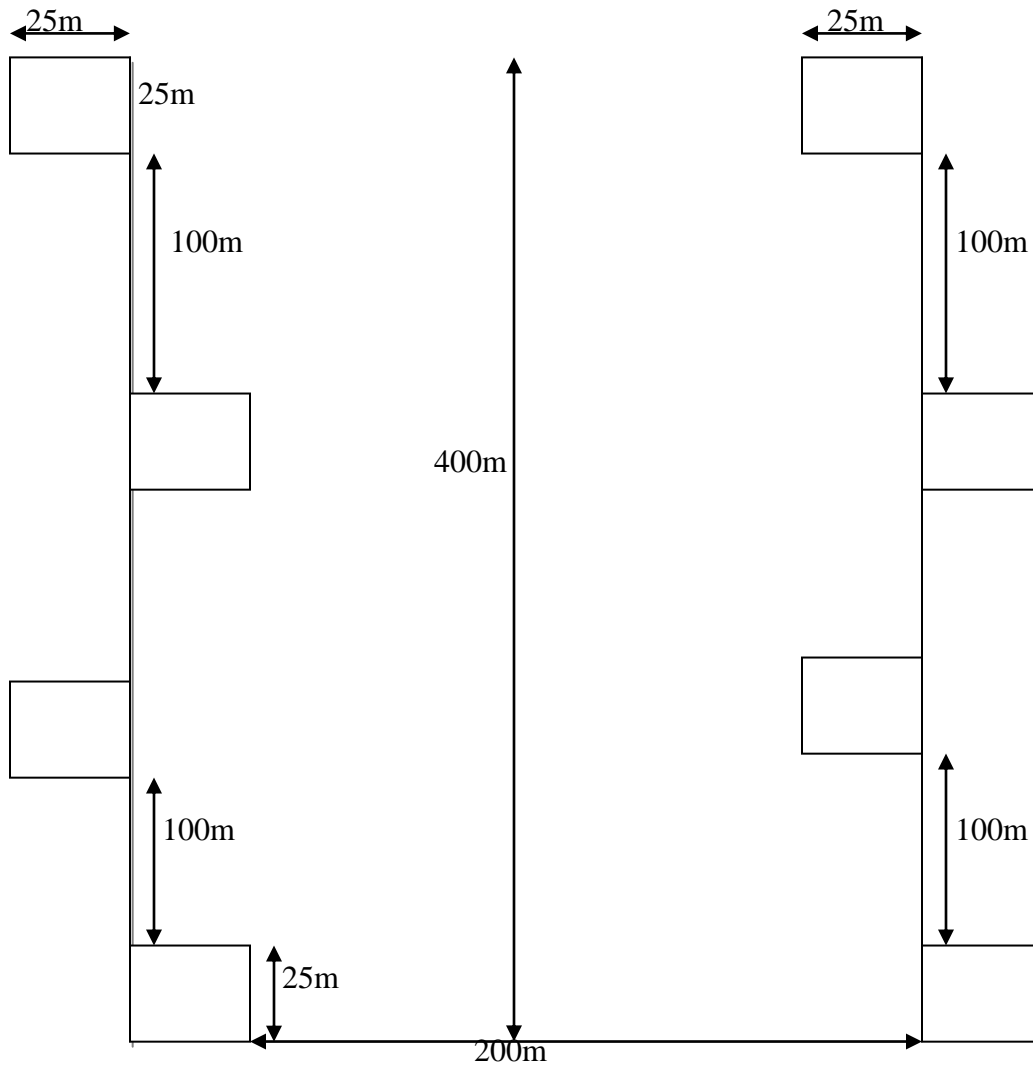


Fig 2: Plot layout with systematic line transects sampling technique

## RESULTS AND DISCUSSION

The forest habitate about 71 stands per hectare of *T. superba* (Table 1) with mean dbh of 48.50 cm and crown diameter of 15.60 m. The result of this study revealed that the tree species is yet to attain its full mean diameter value of 1.3 m as pointed out by FAO (2013). The results obtained by fitting each prediction models are shown in Table 3. For dbh-crown diameter relationship, the dbh was taken as the independent variable, while the crown diameter was taken as the dependent variable. All parameters were found to be significant at the 5% level of probability. The models used for fitting data performed well and produced very similar results. The cubic model gave the best performance according to the values of the statistics used to compare the models in the fitting phase. Consequently, this model was selected. The regression equation was:  $cd = 3.724 - 0.190D + 0.035D^2 - 0.005D^3$

There was a strong positive, non-linear relationship between crown diameter and dbh (Figure 3). Figure 4 showed the plot of the residuals versus crown diameter estimated from the selected model. The regression models between dbh and crown diameter variables were statistically significant ( $P < 0.05$ ). The  $R^2$  value was 93% in the models established. This indicates that dbh is a good predictor of crown diameter for *T. superba*. The cubic model is the best to predict the crown diameter for fitting data ( $R^2 = 93\%$ ;  $MSE = 0.011$ ). Similar studies were also carried out using different tree species (for example Bragg, 2001; Bechtold, 2003; Ige, and Erhabor, 2013), and a strong relationship between dbh and crown diameter was noted. This present study also showed strong relationship between dbh and crown diameter for *T. superba*. From the results of this study, it was noted that crown diameter could be estimated by means of dbh, which is easy to measure for the studies in ground-based forest inventory and stand structure determination for both pure and mixed *T. superba* stands. The dbh-crown diameter relationship can be described by the cubic model in naturally grown *T. superba* stands in Onigambari forest reserve, Nigeria.

Table 3: Model statistics and Parameters estimates of the prediction models

Model No	b <sub>0</sub>	b <sub>1</sub>	b <sub>2</sub>	b <sub>3</sub>	MSE	R <sup>2</sup> (adj)	MR	CV	F-ratio (p<0.05)
1	4.449	0.146	-	-	2.216	0.725	168.262	1.292	82.215*
2	4.995	0.104	0.001	-	2.222	0.727	-0.290	-7.653	41.108*
3	3.724	-0.190	0.035	-0.005	0.011	0.930	-1.4x10 <sup>-15</sup>	-6.44x10 <sup>-16</sup>	30.512*
4	2.010	0.430	-	-	0.275	0.690	0.311	7.219	68.253*
5	5.008	1.017	-	-	0.270	0.709	0.334	6.612	75.286*

MSE = Mean square error, R<sup>2</sup> = Coefficient of determination, MR = Mean of residuals, CV = Coefficient of variation and \* = Significant at p<0.05

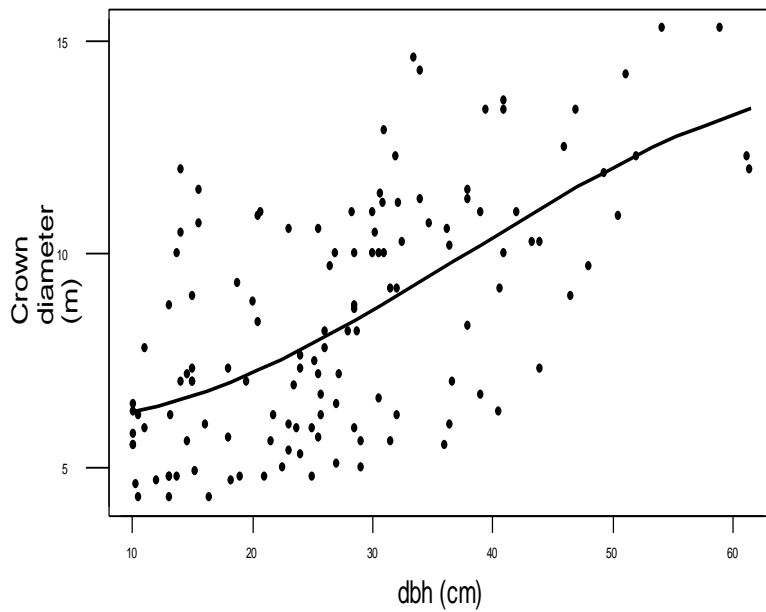


Figure 3: Relationship between dbh and crown diameter (Cubic model)



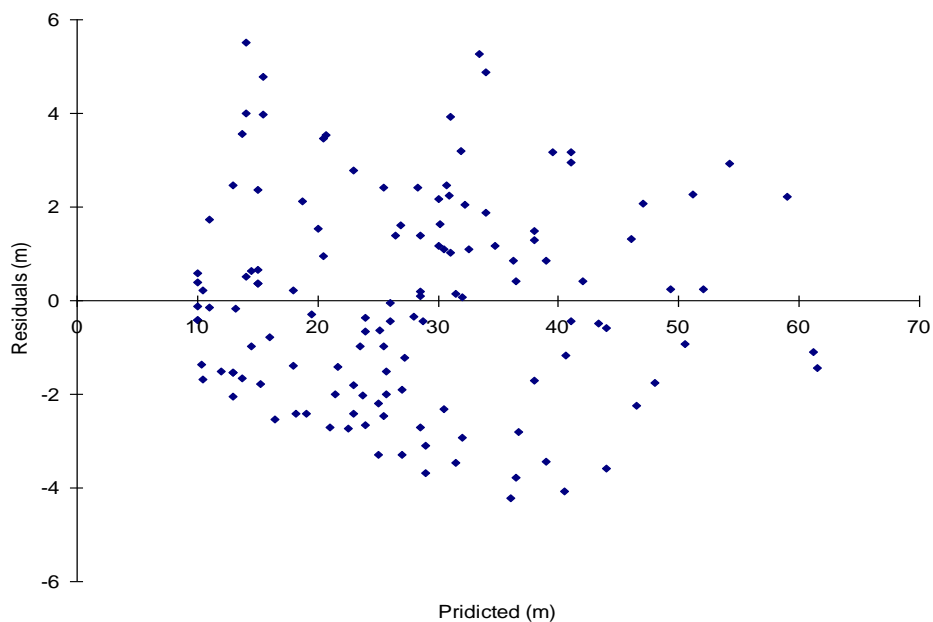


Figure 4: Plots of the residuals versus predicted values for the selected model

### **CONCLUSION AND RECOMMENDATIONS**

It is obvious from this study that dbh can adequately predict the crown diameter very well. The relationship as explained by cubic equation function can further be used to evaluate and estimate the stand volume and basal area in this forest. Deforestation and degradation has been a major and crucial challenge in tree species growth monitoring and modeling in Nigeria. FAO (2010) reported on the rate of deforestation in Nigeria that between 1990 and 2010, Nigeria lost an average of 409,650ha or 2.38% per year. In total, between 1990 and 2010, Nigeria lost 47.5% of its forest cover or around 8,193,000ha. Therefore, sustainable use through conservation and protection of this species will go a long way in making it available on sustainable scale. Hence, the use of cubic equation for modeling dbh-crown diameter is recommended in Onigambari forest reserve.

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