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CROWN RATIO MODELS FOR TROPICAL RAINFORESTS SPECIES IN OBAN DIVISION OF THE CROSS RIVER NATIONAL PARK, NIGERIA

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ABSTRACT
Crown ratio (CR) is a characteristic used to describe the crown size, which is an important element of forest growth and yield. It is often used as an important predictor variable for tree-level growth equations. It indicates tree vigour and is an important habitat variable. It is often estimated using allometry. Modified versions of Logistics, Richards, Weibull and Exponential functions were used to predict CR for tree species in the Oban Division of the Cross River National Park. Systematic sampling technique was adopted in the three study sites (Aking; Ekang and Old-Netim) for plot locations. Two transects of 2km long with a distance of 600m apart were cut in each of the study sites. Four sample plots of 50m×50m were then laid alternately along each transect at 500m intervals. This procedure was repeated in the close-canopy and secondary forests in the three study sites. Forty-eight sample plots were used for the study. Tree variables (Dbh; diameter at the middle and merchantable top; crown diameter; total height; merchantable height; stem quality and crown length were measured on all the trees with Dbh≥10cm. The canopy layer to which each tree belongs was noted. All the measured trees were identified. The Weibull and Exponential functions gave consistent and accurate results in almost all the canopy layers in the two forest types with R^2; SEE values of 0.72; 0.068 and 0.72; 0.067 respectively for the dominant canopy, 0.75; 0.075 and 0.75; 0.074 respectively for the co-dominant canopy. Exponential function produced the best fit models in the study except under intermediate canopy layer, where it was not found suitable for crown ratio predictions. However, the difference in results produced by the two functions is negligible. They are therefore recommended for crown ratio prediction studies in Oban Division of the Cross River National.

Keywords: Tree-crown, predictions, functions, tree variables, canopy-layers

INTRODUCTION
The size of a tree crown is strongly correlated with the growth of the tree. The crown displays the leaves to allow capture of radiant energy for photosynthesis, a key process in tree development. Thus, measurement of the crown is often done to assist in the quantification and understanding of the growth of trees in the stand (Korhonen *et al*., 2006). The ratio of live crown length to the total tree height is known as crown ratio. Crown ratio (*CR*) is the characteristic used to describe the crown size (Hynynen, 1995), which is an important element of forest growth and yield (Cole and Lorimer, 1994). According to Short and Burkhart (1992) and Valentine *et al*. (1994), it is frequently used to predict individual tree growth. In many diameter and height growth equations, tree crown parameters are used as explanatory variables (Monserud and Sterba, 1996), and crown ratio has been used as a predictor of tree vigour (Hasenauer and Monserud, 1996); stand density; competition and survival potential of trees within a forest (Oliver and Larson, 1996). It is a feature of interest in management of many non-timber forest

resources, especially wildlife habitats (McGaughey, 1997; Temesgen *et al*., 2005; Waltert *et al*., 2008).

Tree crown ratio can be predicted directly from other tree variables such as total height and diameter at the breast height (Hasenauer and Monserud, 1996; Pommerening, 2002; Temesgen *et al*., 2005; Adesoye and Oluwadare, 2008). It can also be predicted indirectly from estimates of the height to the base of live crown (Dyer and Burkhart, 1987). Hasenauer and Monserud (1996) have used the logistic functions to predict the mean tree crown ratio, which is always between 0 and 1. The logistic function with normal distribution of errors works under the assumption that the errors are normally, identically, and independently distributed with mean zero and a constant variance. Theoretically, under the assumption of normality the error term can assume a value from negative infinity to positive infinity and the prediction interval for *CR* can be well beyond 0 and 1. Normal distribution approach works fine for the prediction of mean *CR*. However, it might not work for the prediction interval of *CR*, in all other circumstances. An alternative to assuming a normal distribution of errors is to assume the errors follow a beta distribution. This distribution assures that the prediction intervals are always between 0 and 1 (Cassella and Berger, 2002).

Crown ratio is often used as an important predictor variable for tree-level growth equations, particularly for multi-species and multi-layered stands (Temesgen *et al*., 2005). Also, it indicates tree vigour and can be an important habitat variable. Measurement of CR for each tree can be time-consuming and difficult to obtain in very dense stands and for very tall trees, where the base of live crown is obscured but with an established relationship with other tree growth variables, an estimate of CR can be obtained through the use of allometric equations (Temesgen *et al*., 2005). Although Temesgen *et al*. (2005) developed crown ratio models for a multi-species and multi-layered stand in British Columbia, in that study, only five species (*Betula papyrifera*, *Picea glauca*, *Pinus contorta*, *Populus tremuloides* and *Pseudotsuga menziesii* were considered. The models formulated were, however, site specific and not suitable for predictions in the Oban Division of CRNP. Similarly, Adesoye and Oluwadare (2008) developed an interim crown ratio models for a mixed *Tectona grandis* and *Gmelina arborea* stand at the University of Ibadan. However, their models did not include data from the study area. The objective of this study, therefore, was to develop crown ratio models for several tree species in Oban Division of the Cross River National Park under different canopy layers.

METHODOLOGY

The Study Area

The study was carried out in the Oban Division of Cross River National Park (CRNP), Nigeria. It lies within longitudes 8°02' and 8°55'E and latitudes 5°00' and 6°00'N, and covers a land area of 3000km^2 (Ogunjobi *et al.*, 2010). It was carved out of Oban group Forest Reserve in 1991 for the conservation of rich biodiversity. It is located in the Akamkpa Local Government Area of the Cross River State (Fig. 1). It shares border with Korup National Park of Cameroon in the east. It has a raining season of at least nine months (March-November) and receives over 3500mm annually (Ogunjobi *et al*., 2010). It is a large lowland and submontane rainforest situated in the South-southern part of Nigeria along the border with Cameroon. The Cross River and its tributaries drain northern parts of Oban Division, while southern parts are drained by the Calabar, Kwa and Korup Rivers. The terrain is rough and elevation rises from the river valleys to up to 1000m above sea level in mountainous area. The temperature ranges from 25°C to 27°C in January but in July, it rises up to slightly above

30^{o}C. Relative Humidity is between 75% and 95% in January, but towards December, it reduces gradually as a result of harmattan (Bisong and Mfon, 2006). These unique combinations of high rainfall, humidity and temperature have interplayed to develop an equally unique, highly complex and diversity rich vegetation, which is evergreen throughout the year.

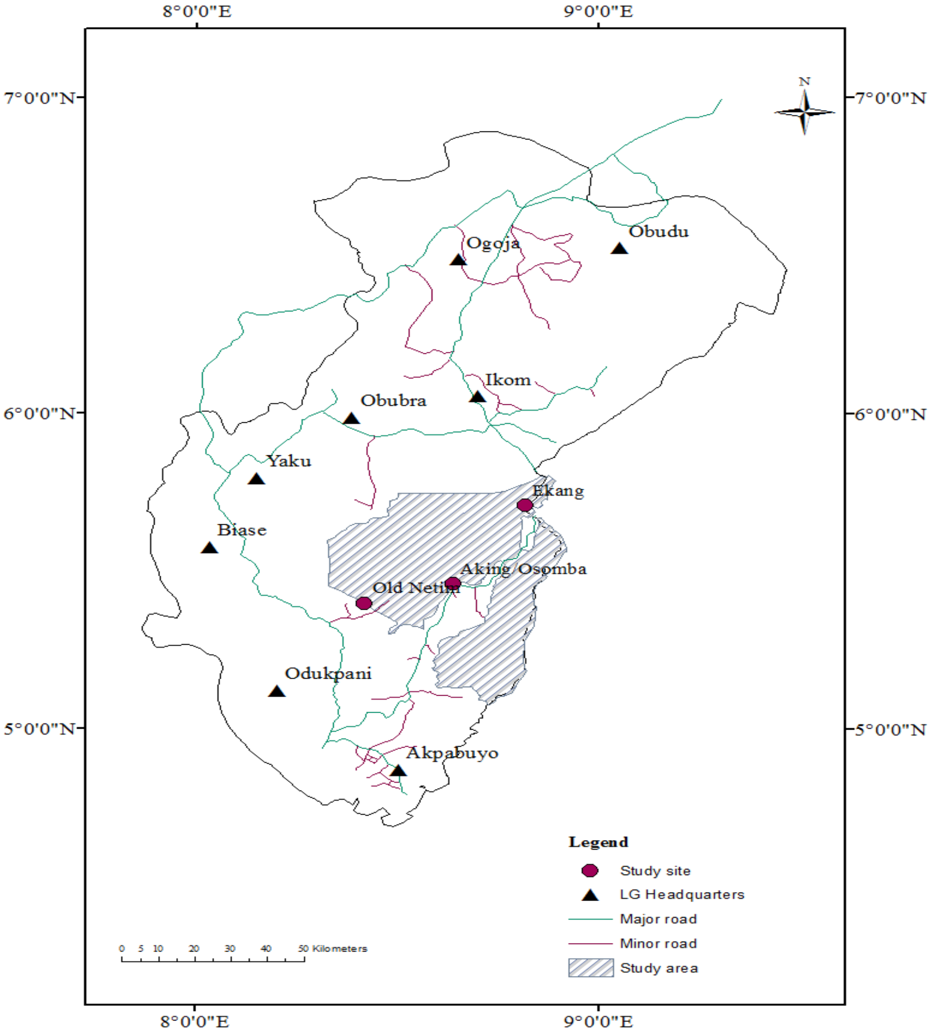

Fig. 1: Map of the Study Area

The vegetation is lowland, evergreen tropical rainforest and characteristic tree species include *Berlinia confusa*, *Coula edulis*, *Hannoa klaineana*, *Klainedoxa gabonensis*, *Khaya ivorensis*, *Terminalia ivorensis*, *Lophira alata*, *Strombosia spp* and *Diospyros spp.* In the less accessible areas, the forest has had little interference, but elsewhere the vegetation has been much influenced by human activities. Exploitation in the buffer zone has resulted in a secondary regrowth. Four vegetation types are distinguishable within the park, these include: high forest, ridge forest, secondary forest and swamp forest (Udo, 2007).

Data Collection

The systematic (line transect) sampling technique was adopted in each of the three study sites (Aking; Ekang and Old-Netim) for plot locations. The starting points of each transect was determined with the aid of Compass and Global Positioning System receiver. Two transects of 2000m in length with a distance of 600m apart were cut in each of the study sites. Four sample plots of 50m×50m were laid alternately along each transect at 500m intervals. This procedure was repeated in the two forest types (close-canopy forest and secondary forest) in each of the three study sites, thus summing up to 4 sample plots per 2km-transect, and a total of 16 sample plots per study site. Forty-eight (48) sample plots were used for the study.

The following data were collected on all the trees with Dbh≥10cm within each of the sample plots: Diameter at breast height (Dbh); diameter at the base (D_b), middle (D_m) and merchantable top (D_t); crown diameter (CD); total height (THT); merchantable height (MHT); stem quality (SQ) and crown length (CL). The canopy layer to which each tree belongs was noted. In addition, all the measured trees within each of the sample plots were identified to species level.

Computation of Model Variables

Basal area computation

The basal area of each tree within each sample plot was computed using the formula:

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

Where, BA = Basal area (m^2); D = Diameter at breast height (1.3m above the ground level).

The basal area for each plot was obtained by adding individual tree basal area in each plot, i.e.

$$BA_p = \sum_{i=1}^{n} BA_1 \quad \ldots\ldots 2$$

Where, BA_P = Basal area per plot; BA_i = Basal area for *ith* tree in the plot. The basal area per hectare was then obtained by multiplying the plot basal area by 4 (4 being the number of 0.25ha-sample plot in a hectare).

Volume estimation

The volume of individual trees per plot was calculated using Newton's formula, as presented by Husch *et al.* (2003):

$$V = \frac{h}{6}\left(A_b + 4A_m + A_t\right) \quad \ldots\ldots 3$$

Where, V = tree stem volume (m^3); h = tree total height (m); A_b, A_m and A_t are cross-sectional areas at the base, middle and top of the trees respectively.

Since $A_i = \dfrac{\pi Di^2}{4}$

The stem volume equation was re-written as:

$$V = \frac{h}{24}\left(\pi D_b^2 + 4\pi D_m^2 + \pi D_t^2\right) \quad \ldots\ldots 4$$

Determination of the volume for each sample plot was done by adding up the volumes of individual trees within each plot. The volume per hectare was then obtained by multiplying the plot stem volume by 4.

Crown Ratio computation

The individual tree crown ratio was computed using:

$$CR = \frac{CLi}{THTi} \quad \text{......} 5$$

Where, CLi = individual tree crown length and THT_i = total height of the *ith* tree. This was computed for each of the species in the stand as a response variable for the crown ration prediction models.

Crown Projection Area

The crown projection area was computed using:

$$CPA = \frac{\pi CD^2}{4} \quad \text{......} 6$$

Where, CD = crown diameter (cm)

Crown Projection area for each plot was obtained as follows:

$$CPA_p = \sum_{i=1}^{n} CPAi \quad \text{......} 7$$

Where, CPA_p = Crown projection area per plot; CPA_i = Crown projection area for *ith* tree in the plot. The Crown projection area per hectare was then obtained by multiplying crown projection area per plot by 4.

Data Analysis

Comparisons of the growth Variables between the two forest types

T-test was used to investigate significant differences between the tree growth variables in the two forest types. T-statistics was computed as:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{S^2 \frac{(N_1 + N_2)}{(N_1)(N_2)}}} \quad \text{......} 8$$

Where, $\overline{X}_1$ = mean of the measured values for a particular growth variable in the close-canopy forest, $\overline{X}_2$ = mean of the measured values for the variable in the secondary forest, N_1 = number of trees sampled in the close-canopy forest, N_2 = number of trees sampled in the secondary forest and S^2 = pooled within-group variance (for independent samples with equal variance). The t has $(N_1$-1) + $(N_2$-1) degrees of freedom.

Analysis of Variance

One-way analyses of variances (ANOVA) were carried out to investigate significant differences in tree growth variables under different canopy layers. The mathematical model for the design is:

$$Y_{ij} = \mu + T_i + e_{ij} \quad \text{......} 9$$

Where, μ = overall mean, T_i = effect of the canopy layers, $e_{i,j}$ = experimental error.

Crown Ratio Models

Four non-linear regression models were fitted to the tree growth variables in the two forest types. The following non-linear regression functions were fitted to the tree growth data.

Logistics:

$$CR = \frac{a_0}{a_1 + a_2 e^{(m-cX)}} \qquad (10)$$

Richards:

$$CR = \frac{a_0}{a_1 + a_2 e^{(m-cX)^{1/k}}} \qquad (11)$$

Weibull:

$$CR = a_0(a_1 + a_2 e^{-kX^m}) \qquad (12)$$

Exponential:

$$CR = a_0(a_1 + a_2 e^{-kX}) \qquad (13)$$

Where *CR*, = the tree crown ratio; X = a linear function of tree sizes; a_0 is asymptote; a_1, a_2, c, k and m are function parameters.

Model description

The variables that are commonly used for crown ratio modelling are tree age; tree size (diameter, height, height/diameter ratio); stand density (number of trees/ha, basal area); maximum tree dimension (diameter); mean tree dimension (diameter, dominant diameter), site productivity (dominant height, site index) and stand-level competition. For this study, tree age was not included since the age structure of an uneven-aged forest is highly heterogeneous and its determination in practical forestry is not meaningful, and also very rear on research plots (Laiho *et al*., 1995; Adekunle *et al.*, 2004). Thus, age is not very important for modelling in tropical rainforest. Several other researchers such as Vanclay (1994), Okojie (1996) and Akindele (2005) have used surrogates of age (diameter, basal area and site form) during modelling.

Given that the crown ratio models were intended for multi-species and multi-layered stands, site index was intentionally excluded from the models (Vanclay, 1994 and Akindele, 2005). The linear function X was expressed as a combination of tree size (diameter, stem quality, merchantable height and total height) and tree basal area. All the growth variables were tried with individual tree crown ratio as the response variable (Y). For all the models, the following statistics were computed:

Standard Error of Estimates (SEE)

$$SEE = \sqrt{\frac{\sum_{i=1}^{n} \hat{e}_i^{\,2}}{n-k}} \qquad (14)$$

Coefficient of Determination (R^2)

$$R^2 = 1 - \frac{SSE}{SST} \qquad (15)$$

Where, $\hat{e}$ is the difference between the measured (y_i) and the estimated crown ratio values $(\hat{y})$; *SSE* is the error sum of squares, *SST* is the total sum of squares, *n* is the number of trees in the model-fitting data set, and *k* is the number of parameters in the fitted models. Evaluation of the functions was also achieved through the observation of the nature of contribution of the parameter estimates and the computation of mean residual, standard deviation of the residual and the coefficient of variation (CV) of the residual (Adesoye and Oluwadare, 2008). Different versions of the logistic, Weibull, Richards and exponential functions were tried on all the tree growth variables. The parameter estimation of these non-linear functions were based on the least squares method associated with Quasi-Newton minimization technique of non-linear estimation option of STATISTICA version 7.0 (2004). Both the significance and the stability of the parameters estimates were checked based on the asymptotic t-statistic and standard errors of the parameters. When the parameter estimate is not significantly different from zero the variables and the parameter were discarded.

Model Evaluation

Model evaluation was based on the computation of the following statistics for the comparisons of the selected functions:

Significance of Regression (F-ratio)

This tested the overall significance of the models. The critical value of F (F-tabulated) at p<0.05 level of significance was compared with the F-ratio (F-calculated). Where the variance ratio (F-calculated) was greater than the critical values (F-tabulated), such equation was significant and was accepted for crown ratio prediction.

Mean Prediction Residual (MPR)

$$MPR = \frac{\sum_{i=1}^{n} (Observed - \Pr edicted)}{n} \quad \ldots\ldots 16$$

Residual Coefficient of Variation (RCV)

Residual coefficient of variation (RCV) was computed to address the weakness of residual standard deviation (RSD). It is should be noted that standard deviation or variance cannot be very useful in comparing two or more series where either the units of measurement are different or the mean values are different. Coefficient of variation therefore takes care of this problem. The RCV was computed as:

$$RCV = \frac{RSD}{MPR} \quad \ldots\ldots 17$$

Prediction Sum of Squares (PRESS) statistic

This was computed as:

$$PRESS = \sum_{i=1}^{n} (Observed - \Pr edicted)^2 \quad \ldots\ldots 18$$

RESULTS AND DISCUSSION

Table 1 presents the t-tests for the comparison of the means of the tree growth variables between the two forest types. The result shows that there were significant differences between the mean tree total heights (THT) and diameters at breast height (Dbh) under the two forest types (P = 0.2022) and (P = 0.4312) respectively. The comparison of mean tree stem quality (SQ) in the two forest types revealed a significant difference as P< 0.05. This implies that the mean SQ in the close-canopy forest was significantly different from that obtained in the secondary forest. The test for the comparison of the mean tree crown diameters (CD) between the two forest types showed a significant difference (P<0.05). This implies that the mean tree crown diameters in the two forest types were significantly different from each other. The result revealed that the mean tree basal area (BA) obtained in the close-canopy forest was not significantly different from that obtained in the secondary forest as P>0.05. The tests for the crown projection area (CPA), stem volume (SV) and crown ratio (CR) revealed no significant differences in the two forest types since P>0.05 in each of the cases. This implies that the mean values obtained in the close-canopy forest were not significantly different from those obtained in the secondary forest. The lack of significant differences between most of the tree growth variables in the two forest types necessitated the fitting of the regression models into the pooled data from the two forest types. However, there were significant differences among growth variables under different canopy layers, hence, the four models were fitted to the data set on the canopy layer basis (Table 2).

Table 1: t-tests for the tree growth variables between the two forest types

Variables	Forest Type	N	Mean	S.D	df	t-stat	p-value
THT	CCF	947	24.3946	8.3027	1724	1.2757	0.2022
	SCF	779	24.9090	8.3762			
Dbh	CCF	947	35.4524	27.9940	1724	0.7873	0.4312
	SCF	779	34.4342	25.1213			
SQ	CCF	947	16.3046	6.9377	1724	2.0099	0.0446*
	SCF	779	16.9693	6.7112			
CD	CCF	947	6.2885	4.0573	1724	2.1413	0.0324*
	SCF	779	6.7165	4.2215			
BA	CCF	947	0.1602	0.4221	1724	1.0083	0.3134
	SCF	779	0.1426	0.2664			
CPA	CCF	947	43.9746	70.0042	1724	1.5750	0.1154
	SCF	779	49.4096	72.9387			
SV	CCF	947	2.7180	7.6144	1724	0.6117	0.5408
	SCF	779	2.9366	7.1086			
CR	CCF	947	0.3366	0.1487	1724	2.6502	0.0812
	SCF	779	0.3182	0.1369			

**significant (p<0.05); CCF: closed canopy forest; SCF: secondary forest; THT: tree total height; Dbh: diameter at breast height; SQ: stem quality; CD: crown diameter; BA: basal area; CPA: crown projection area; SV: stem volume; CR: crown ratio.*

Table 2: Mean separations for the tree growth variables under the four canopy layers

Canopy layer	Mean values of the tree growth variables							
	THE	**MHT**	**SQ**	**DBH**	**CD**	**CL**	**BA**	**CPA**
Dominant	41.3831[a]	28.0465[a]	27.8769[a]	80.6204[a]	12.6689[a]	13.3808[a]	0.6580[a]	150.8611[a]
Co-dominant	32.7893[b]	23.1286[b]	22.5645[b]	47.3846[b]	8.3672[b]	10.1906[b]	0.2257[b]	66.4909[b]

Intermediate	22.6100^{c}	15.1963^{c}	15.2357^{c}	28.7036^{c}	5.6794^{c}	7.3647^{c}	0.0903^{c}	33.0034^{c}
Suppressed	13.5125^{d}	8.3704^{d}	8.5697^{d}	20.5891^{d}	4.0641^{d}	4.9407^{d}	0.0446^{d}	20.3635^{d}
	SV	**CR**	**SF**	**SC**				
Dominant	15.6432^{a}	0.3587^{a}	0.5986^{a}	94.2875^{a}				
Co-dominant	4.6657^{b}	0.3278^{b}	0.5730^{b}	82.4983^{b}				
Intermediate	1.1730^{c}	0.3293b^{c}	0.5560^{c}	73.6815^{c}				
Suppressed	0.3907^{c}	0.3093^{c}	0.5340^{d}	64.9771^{d}				

NB: Means with the same alphabet as superscripts under each column heading are not significantly different from each other

Table 3: Tree crown ratio models, parameter estimates and fit statistics for dominant canopy layer

Function	Parameter	Estimate	SE	t (df =127)	P-value
Logistic:	a_0	-2.3959	0.2065	11.6023	0.0000*
$Cr = \frac{a_0}{1-e^{(1-a_1(BA)+a_2SQ)}}$	a_1	0.0530	0.0108	4.9200	0.0000*
	a_2	0.0435	0.0030	14.5900	0.0000*
R^2= 0.71; SEE = 0.069					
Richards:	a_0	11.1416	0.8969	12.4224	0.0000*
$Cr = \frac{a_0}{1-e^{(1-a_1(BA)+a_2SQ)^4}}$	a_1	0.0110	0.0023	4.8540	0.0000*
	a_2	0.0089	0.0006	15.8668	0.0000*
R^2= 0.71; SEE =0.069					
Weibull:	a_0	-0.7304	0.0545	13.3968	0.0000*
$Cr = a_0 + e^{(-a_1(BA)+a_2SQ)^{1/2}}$	a_1	-0.0534	0.0106	5.0546	0.0000*
	a_2	-0.0339	0.0038	8.9818	0.0000*
R^2= 0.72; SEE = 0.068					
Exponential:	a_0	-1.8605	0.0387	48.1088	0.0000*
$Cr = a_0 + e^{(-a_1(BA)+a_2(SQ))}$	a_1	0.0141	0.0028	4.9764	0.0000*
	a_2	-0.0083	0.0006	13.1690	0.0000*
R^2= 0.72; SEE = 0.067					

Table 4: Tree crown ratio models, parameter estimates and fit statistics for Co-dominant canopy layer

Function	Parameter	Estimate	SE	t (df =328)	P-value
Logistic:	a_0	-2.6434	0.1391	19.0014	0.0000*
$Cr = \frac{a_0}{1-e^{(1-a_1(BA)+a_2SQ)}}$	a_1	0.1535	0.0241	6.3585	0.0000*
	a_2	0.0601	0.0024	24.7192	0.0000*
R^2= 0.73; SEE = 0.077					
Richards:	a_0	12.1575	0.5959	20.4025	0.0000*
$Cr = \frac{a_0}{1-e^{(1-a_1(BA)+a_2SQ)^4}}$	a_1	0.0312	0.0049	6.3654	0.0000*
	a_2	0.01213	0.0005	26.7033	0.0000*
R^2= 0.74; SEE = 0.076					
Weibull:	a_0	-0.6935	0.0333	20.8053	0.0000*
$Cr = a_0 + e^{(-a_1(BA)+a_2SQ)^{1/2}}$	a_1	-0.1356	0.0207	6.5379	0.0000*
	a_2	-0.0461	0.0030	15.1618	0.0000*
R^2= 0.75; SEE = 0.075					
Exponential:	a_0	-1.8394	0.0224	82.109	0.0000*
$Cr = a_0 + e^{(-a_1(BA)+a_2(SQ))}$	a_1	-0.0338	0.0052	6.4894	0.0000*
	a_2	-0.0108	0.0005	23.4695	0.0000*
R^2= 0.75; SEE = 0.074					

Table 5: Tree crown ratio models, parameter estimates and fit statistics for intermediate canopy layer

Function	Parameter	Estimate	SE	t (df =1006)	P-value
Logistic: $Cr = \frac{a_0}{1-e^{(1-a_1(BA)+a_2SQ)}}$	a_0	-2.2675	0.0649	34.9416	0.0000*
	a_1	0.1377	0.0154	8.9593	0.0000*
	a_2	0.0752	0.0019	39.0398	0.0000*
R^2=0.71; SEE =0.078					
Richards: $Cr = \frac{a_0}{1-e^{(1-a_1(BA)+a_2SQ)^6}}$	a_0	30.7733	0.8062	38.1712	0.0000*
	a_1	0.0186	0.0021	8.7469	0.0000*
	a_2	0.0099	0.0002	43.1823	0.0000*
R^2= 0.71; SEE =0.078					
Weibull: $Cr = a_0 + e^{(-a_1(BA)+a_2SQ)^{1/4}}$	a_0	-0.3530	0.0335	10.5283	0.0000*
	a_1	-0.3973	0.0490	8.1147	0.0000*
	a_2	-0.1734	0.0136	12.7098	0.0000*
R^2= 0.70; SEE = 0.079					
Exponential: $Cr = a_0 + e^{(-a_1(BA)+a_2(SQ))}$	a_0	-	-		-
	a_1	-	-		-
	a_2	-	-		-

Table 6: Tree crown ratio models, parameter estimates and fit statistics for suppressed canopy layer

Function	Parameter	Estimate	SE	t (df =253)	P-value
Logistic: $Cr = \frac{a_0}{1-e^{(1-a_1(BA)+a_2SQ)}}$	a_0	-1.5093	0.1091	13.8374	0.0000*
	a_1	0.4424	0.0573	7.7271	0.0000*
	a_2	0.0827	0.0079	10.5390	0.0000*
R^2= 0.43; SEE =0.11					
Richards: $Cr = \frac{a_0}{1-e^{(1-a_1(BA)+a_2SQ)^2}}$	a_0	2.5166	0.1747	14.4049	0.0000*
	a_1	0.2039	0.0271	7.5118	0.0000*
	a_2	0.0374	0.0034	11.0438	0.0000*
R^2= 0.43; SEE = 0.109					
Weibull: $Cr = a_0 + e^{(-a_1(BA)+a_2SQ)^{1/2}}$	a_0	-1.0015	0.0296	33.8913	0.0000*
	a_1	-0.3857	0.0703	5.4889	0.0000*
	a_2	-0.0474	0.0051	9.3024	0.0000*
R^2= 0.38; SEE =0.112					
Exponential: $Cr = a_0 + e^{(-a_1(BA)+a_2(SQ))}$	a_0	-2.0936	0.0259	80.2593	0.0000*
	a_1	-0.1136	0.0165	5.2482	0.0000*
	a_2	-0.0127	0.0012	10.4356	0.0000*
R^2= 0.37; SEE = 0.112					

The selected version of the Logistics, Richards, Weibull and Exponential functions, their parameter estimates and fit statistics for different canopy layers are presented in Tables 3, 4, 5 and 6 respectively. Tree basal area and stem quality were found to consistently predict CR in all the functions. In order to avoid convergence problems associated with the fitting of Richards and Weibull functions to the data set, the index parameters (k and m) were restricted in the four sets of the models. The final values of k = 4 and m = 2^{-1} were obtained for the two functions under the dominant and co-dominant canopy layers; k = 6 and m = 4^{-1} were obtained for the two functions under the intermediate canopy layer; while k = 2 and m = 2^{-1} were obtained for the two functions under the suppressed canopy layer in the sets of models. The predictors were rather redundant for the Exponential function under the intermediate canopy layer; hence, no acceptable equation was obtained for CR predictions under this layer. There were minor differences in the values of R^2 and SEE for the four functions under different canopy layers. In the dominant layer, the R^2 values were generally high with low values of SEE. The values of R^2 ranged between 0.71 and 0.72 (Table 2). The SEE values ranged between 0.067 and 0.069. Under this layer, Weibull function gave the best fit to the data set with R^2 = 0.72; SEE = 0.067. This was followed by the Exponential function with R^2 = 0.72; SEE = 0.068. On the whole, the four functions gave good fits to the data set under the dominant canopy layer. All the parameter estimates retained for the four functions under this layer were found to be significantly different from zero.

Table 7: Evaluation of the four functions under the four canopy layers

Canopy layer	Function	MPR	RSD	RCV	PRESS
Dominant	Logistics	0.000805	0.0682	84.7205	0.2093
	Richards	0.000779	0.0681	87.4198	0.2024
	Weibull	0.0000001	0.0665	665000	0.000022
	Exponential	0.0000001	0.0665	665000	0.000022
Co-dominant	Logistics	0.00326	0.0782	23.9877	2.1590
	Richards	0.00157	0.0763	48.5987	1.0378
	Weibull	0.0000001	0.0741	741000	0.000064
	Exponential	0.0000018	0.0745	41388.8889	0.00117
Intermediate	Logistics	0.000581	0.0780	134.2513	1.1729
	Richards	0.0000278	0.0744	2676.2590	0.0476
	Weibull	0.0000001	0.1120	1600000	0.000015
	Exponential	-	-	-	-
Suppressed	Logistics	0.003155	0.1080	34.2313	1.6152
	Richards	0.001095	0.1078	98.4475	0.5603
	Weibull	0.00000001	0.0790	158000000	0.00000024
	Exponential	0.000000001	0.1127	2254000000	0.0000001

MPR: mean prediction residual; RSD: residual standard deviation; RCV: residual coefficient of variation; PRESS: prediction sum of squares statistics.

Under the co-dominant layer, R^2 values for all the functions were also high with lower values of SEE than the dominant layer. The R^2 values ranged between 0.73 and 0.75. The SEE values ranged between 0.074 and 0.075 (Table 3). In this layer, all the parameter estimates for the four functions were significantly different from zero as well with Exponential function given the best fit. Similarly, there were high R^2 values and low values of SEE for the Logistics, Richards and Weibull functions in the intermediate canopy layer. The R^2 values were between 0.70 and 0.71 while the SEE values ranged between 0.078 and 0.079 (Table 4). The Logistics and Richards had the highest R^2 value of 0.71 and the lowest SEE values of 0.078 each. The Weibull function least explained the CR under this layer. The parameter estimates for the three functions under this layer were significantly different from zero. However, the Exponential function did not produce any acceptable model for the tree CR in the intermediate layer, as the functions tried revealed that the predictors were rather redundant.

The four functions gave lower values of R^2 and higher values of SEE under the suppressed layer when compared with the values obtained in the other three canopy layers (R^2-values of between 0.37 and 0.38) as shown in Table 5. However, all the parameter estimates were significantly different from zero. The Logistics and Richards functions gave the best fit to the data set under this canopy layer. The Exponential function list explained the CR. The evaluation statistics obtained for the four functions under the four layers are presented in Table 7. The table includes the measures of precisions and the biases associated with the four functions under different canopy layers. The tree basal area and stem quality gave best fits to the data set and were found to be important in defining the tree crown ratios for the two forest-types in Oban Division of the Cross River National Park. The suitability of all the other tree growth variables was investigated. They were, however, not significant and gave very poor fits to the data set. These other variables failed to explain the tree crown ratios in all the canopy layers, and were, therefore, not included in the models presented.

The R^2 values for the four functions were consistently high under the dominant, co-dominant and intermediate layers with very low values of standard errors of estimates (SEE). The suppressed layer, which gave a much lower fit to the data set in all the functions, however produced significant results for all the estimated parameters in all the functions. The R^2 values obtained for the four functions were generally higher compared to those reported by previous workers for less diverse ecosystems (Temesgen *et al*., 2005; Adesoye and Oluwadare, 2008) with much lower SEE values. This indicated better fits of the four functions than those reported by previous workers. The four functions, except Exponential under the intermediate layer, gave consistent results for the fit indices.

The mean prediction residual (MPR) values associated with all the functions under the four canopy layers were extremely low and found to be negligible. The residual standard deviation (RSD) values for the four functions were somewhat similar under each of the four canopy layers. However, the residual co-efficient of variations (RCV) were much different for the four functions in all the canopy layers. The RCV values obtained for the four functions under the four canopy layers are lower compared to the values reported by Adesoye and Oluwadare (2008) for the same set of functions. The values were much larger for the Weibull and Exponential functions. These two functions also had the lower values for the fit indices under the four canopy layers compared to Logistics and Richards. Nevertheless, the Weibull and Exponential functions gave the least PRESS statistics in all the canopy layers. The PRESS statistics obtained were generally lower than the values reported by Adesoye and Oluwadare (2008). The suitability of Richards and Logistics functions were further confirmed as observed by Soares and Tome (2001) and Temesgen *et al.* (2005). Moreover, the Weibull and Exponential functions were found, even more suitable in the study as they gave higher R^2-values for all the canopy layers, except the suppressed. This disagrees with the reports by Soares and Tome (2001), Temesgen *et al.* (2005), Adesoye and Oluwadare (2008), where suitability of only the Richards and Logistic functions were established. This may be as a result of the variables used in their studies. It may also be due to the larger data set used in this study, and higher species and structural diversities in the ecosystem. Nevertheless, the fit of Exponential function to the data set under intermediate layer produced no good result.

CONCLUSION

Based on the evaluations of the four functions used in this study for tree crown ratio modelling, the Weibull and Exponential functions gave the most consistent and accurate results in almost all the canopy layers, going by their fit indices. On the whole, exponential function produced the best result in this study. However, the difference from the Weibull function is negligible. The two functions are therefore recommended for crown ratio predictions studies in the Oban Division of Cross River National Park, Nigeria. The Logistic and Richard functions also gave significant results, but the other two functions are preferable. The Exponential function was not found suitable for tree crown ratio prediction under the intermediate canopy layer of the area. The four functions are tree basal area and stem quality dependent. Since the four functions produced good results for the tree crown ratio modelling, they are recommended for future studies in the Oban Division of the Cross River National

Park and other areas with similar ecosystem structure. For this study, the species were pooled, as more data are generated in the future, the suitability of these functions on species bases can be investigated.

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