NON-LINEAR TREE CROWN RATIO MODELS IN INTERNATIONAL INSTITUTE OF TROPICAL AGRICULTURE FOREST, IBADAN

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ABSTRACT

Assessment and monitoring of forest is a key tool for environmental purposes which are an integral part to sustainable management of the forest. Crown ratio is generally used to describe the ratio of the crown length to tree total height. The prediction of crown ratio is based on empirical models which aid in the development of accurate predictions for both individual and stand growth, as well as yield, which are useful tools for analyzing a variety of management and decisions making. However, no single model can effectively provide enough information for all stages of decision-making. As such, this study was aimed at the development of crown ratio for International Institute of Tropical Agriculture (IITA) Ibadan. Data used was collected from International Institute of Tropical Agriculture (IITA) Ibadan, Nigeria. Simple systematic line transects of four parallel transect of 200m apart were used for plot laying. Sixteen sample plots of 25m × 25m were laid for data collection, all tree with Diameter at Breast Height (dbh) ≥ 10cm were measured to determine No of stand per hectares (N_i/ha), Quadratic mean dbh per hectare (DQ/ha) and Volume per hectare (V/ha). The entire response variable for predicting tree crown ratio model was measured and computed (Crown Length - CL, Crown Diameter - CD, Tree Slenderness Coefficient - TSC, Tree Total Height - TH and Merchantable Height - MH). Data were analyzed using both descriptive and inferential statistic using non-linear regression packages on R software at $\alpha_{0.05}$. Comparison of models was done using RMSE, R^2, AIC and BIC. The stand comprises of 389 stem ha^{-1}. The DBH, TH, N/ha, DQ, TSC, V and CD values ranged from 10– 170cm, 7.7m – 38.1m, 96 – 704, 18.047 – 52.655cm, 22 – 225%, 0.003 – 24.676m^3 and 3 – 13.7m, respectively. The selected model for crown ratio is the Modified exponential model: CR= -0.81745+exp $^{(0.05451CL-0.0934THT)}$ (RMSE = 0.027, AIC = -1278.412, BIC = -1263.705 and R^2= 0.906). The established crown ratio models have a substantial association with CL and THT, and may be successfully employed for crown ratio prediction investigations in IITA.

Keywords: Tree growth characteristics, Slenderness coefficient, Crown ratio

Correct Citation of this Publication
Ige P. O. and Komolafe O. O. (2022). Nonlinear tree crown ratio models in international Institute of Tropical Agriculture Forest, Ibadan. *Journal of Research in Forestry, Wildlife & Environment,* 14(1): 27 – 42

INTRODUCTION

Tree crown condition is one of the most first visible and viable indicators that physically describe the forest visibility and it have been widely and general used as indicators of forest health, forest tree health and vitality (Sharma *et al*., 2018). It was reported by Zarnoch *et al.* (2004) that the effects of natural and anthropogenic stress on a forest are firstly observed by the decline of the forest crown which convert the photosynthetic that the tree required for its growth which also have direct effect on the understory flora and fauna of the forest. Crown ratio is the portion of the tree height which supports live green foliage which is the distance end to end of the tree with branches, divided by the total tree height (Azuma *et al.*,2004). This crown ratio provides an approximation of the photosynthetic ability of the tree. Trees with larger live crown are generally refers to as healthy and fast growing trees as asserted by (Zarnoch *et al.*, 2004). The crown dimension plays a significant role in forest growth and yield models (Soares and Tome, 2001). Crown provides shade, temperature control, food, habitat for many organisms. Crown condition indicator are been used to observe noticeable changes in crown condition, relate crown condition to tree growth or stress such as insects and diseases, serve as an indicator of climate change and also helps in evaluating appropriateness of stand for wildlife and bird species (Mcgaughey, 1997). Crown ratio is also useful in determining the competition and survival potential of a tree (Oliver and Larson, 1996) as well as wind firmness (Navratil, 1997). Crown ratio is often used as predictor variables for tree growth and also indicates tree dynamism and vitality which is very useful in forest health assessment as reported by Popoola and Adesoye (2012). Canopy fire behavior and canopy fuel characteristic are crown features which are been influenced by crown ratio (Li *et al*., 2020). The size of the crown is an important measure of tree vigour which is widely used to predict growth and yield of trees and forests (Hasenauer and Monserud, 1996).

Prediction of crown ratio has been based on empirical formula, the empirical model used in crown ratio could be a function of variables of competition measure (density and crown competition factor) and also site (aspect, elevation and the slope) literature of success includes (Wykoff *et al.,* 1982; Monserud and Sterba, 1996; Oyebade and Onyeoguzoro, 2017). Various empirical models used in predicting the crown ratio are found in the literatures with their various advantages and disadvantages. The weilbul probability density distribution function has been used to model the crown ratio (Leites *et al.,* 2009; Adeyemi *et al.,* 2013), the logistic function has also been used in crown ratio prediction by Ritchie and Hann (1987) with their value constrained to be between 0 and 1, the exponential function was also used by Leites *et al.* (2009) which is simple and may present meaningful parameters but its limitation is that it can predict CR values greater than 100% in the extremes of the data. The necessity of crown ratio models in decision making in forestry has resulted to varieties of researches on crown models such as crown diameter models (Ige and Erhabor, 2013), crown projection ratio model (Chukwu *et al.*, 2020) and crown ratio model (Popoola and Adesoye, 2012; Adeyemi *et al.*, 2013).

Studies on crown ratio in natural stand is limited as numerous of researches carried out in Nigeria focuses majorly on plantation. Plantation are intensively managed and composed of one or two species with the same age class and also characterized with regular tree spacing as compare to a natural stand of uneven age with irregular tree spacing. No single type of model is sufficient or can effectively provide enough information for all stages of decision making or predict all types of stand structure. As such, this study aimed in developing crown ratio models for several tree species in a natural stand of International Institute of Tropical Agriculture Ibadan.

MATERIALS AND METHODS

Study Area

This study was carried out in International Institute of Tropical Agriculture (IITA) Forest (Fig. 1). IITA forest has a humid tropical climate with well-known wet and dry seasons, with the wet season beginning from March and ends in October and dry season that last from November to February, it has an average daily temperature of about 21°C to 23°C, maximum temperature ranges from 28°C to 34°C. The rainfall pattern of the forest is bimodal which is between 1300 – 1500mm and falls between the month of May and September. The mean daily relative humidity is 64 -83% (Oluyinka, 2020). It is characterized with a low lying and gentle undulating topography. The elevation ranges between 243m to 292m. The parent rock materials of the soil are been forms through the underlying crystalline and banded gneiss which weathers to form site-specific soils. In the upland areas clay, quartz gravel and sand are predominant soil types while the bottom of the valley has poorly drained clay and sandy soils. Some part of IITA forest has a highly diverse plant species. The vegetation of this area could be classified as tropical semi-deciduous forest with diverse of vegetation types ranging from derived savanna, secondary forest and riparian types.

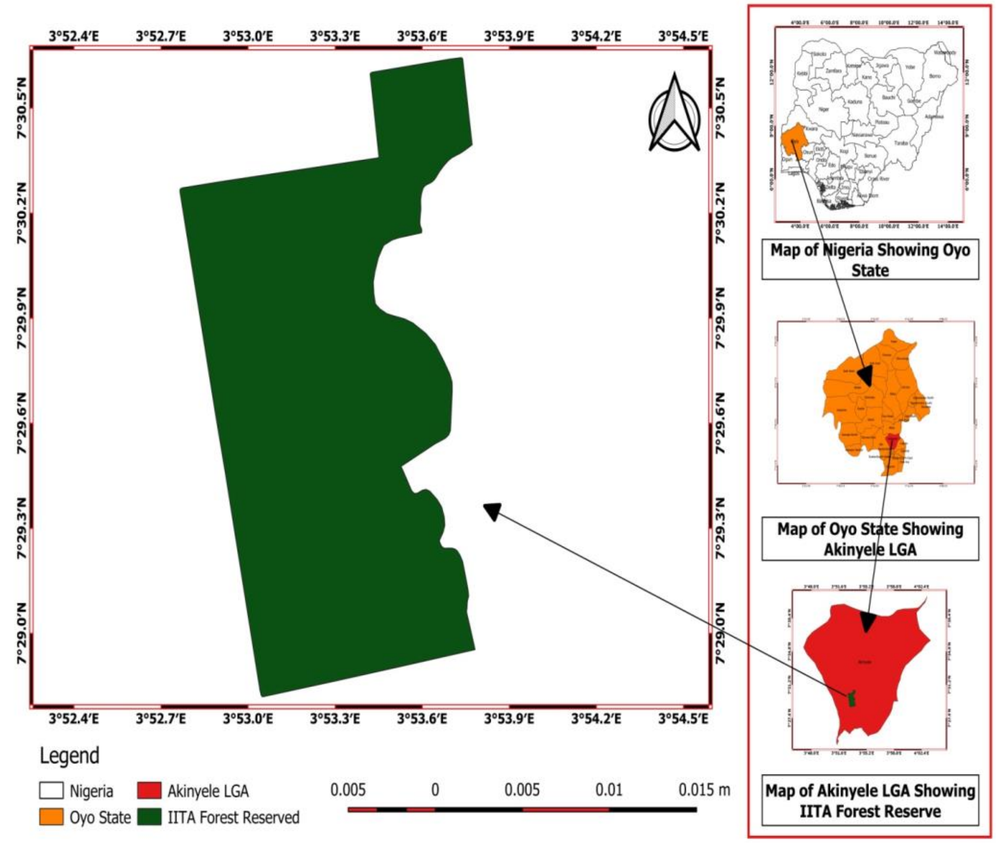

Figure 1: Map of IITA Forest Reserve.

Sampling Technique and Data Collection

Simple systematic line transect was adopted for this study for plots laying for data collection. Sixteen (16) temporary sample plots were used for this research work. In laying of plots for data collection, four parallel transects of equal distance (270m) was delineated at 200m apart for this study. A total number of 4 sample plot of equal size (25m x 25m) were laid alternatively on each transect and 50m interval distance offset away from each sample plot was observed so as to decrease replication of tree species. Offset of 20 meters was measured at the beginning of each transect so as to minimize edge effect (Fig. 2), On each sample plot, all trees with Diameter at Breast Height (DBH) $\geq$ 10cm were identified and measured. To estimate volume per stand, the diameters at the base, middle and top; merchantable height and the total height of all the trees in each plot were measured using Spiegel relaskop. The crown diameter (m) and crown length (m) were measured while other variables used in modelling the crown ratio were also estimated using relevant established methods.

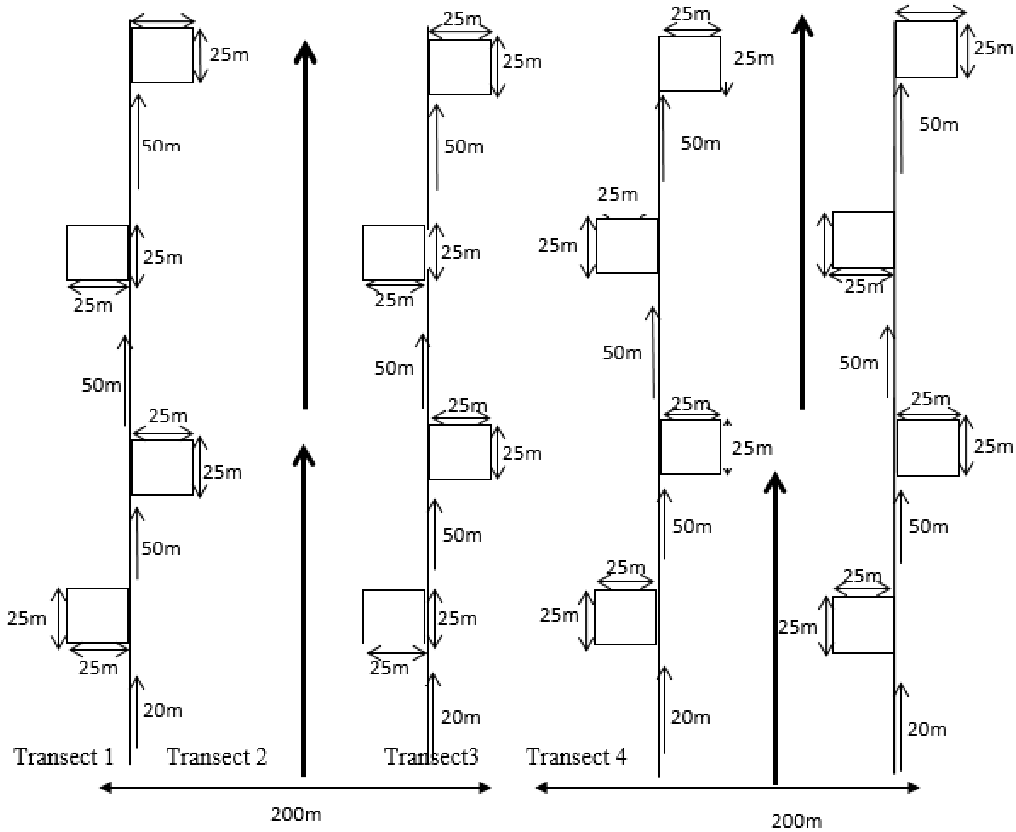

Figure 2: Systematic line transects sampling technique for Plot layout.

Disclaimer
This study is a subset of a robust or big research/study carried out in the study area by the authors.

Tree Crown Analyzes
The entire tree Crown indices were computed for each of the species in the sample plot, which serves as a response for predicting the crown ratio models

Crown Ratio
Tree crown ratio was computed for each of the tree crown in the stand using this formula:

$$Crown\ Ratio = \frac{CL_i}{THT_i} \ldots (1)$$

Where: CL_i is individual crown length (m) and THT_i is the Total height (m) of the tree

Tree Crown Competition
Tree crown competition factor was computed using this formula as used by Oyebade and Onyeoguzoro (2017)

$$CW = b_0 + b_1 D \ldots .. (2)$$

Where: CW is the crown width (m), b_0 and b_1 are the regression parameter and D is the Diameter (cm)

Crown Diameter
Crown diameter was computed using this formula:

$$CD = \sum r_i/2 \ldots \ldots (3)$$

Where: CD is Crown diameter (m), $\sum r_i$ is the summation of the projected crown radii measured on four axes.

Crown Ratio Model Development

Nonlinear crown ratio models were adapted for this study. Generalized models used for tree height prediction such as Logistic model, Chapman-Richard, Polynomial and Exponential were modified and selected as candidate equation functions to model crown ratio for the study area. The crown ratio is the dependent variable and selected stand growth variables such as tree height, crown length and tree slenderness coefficient (the ratio of tree height to diameter) as the independent variable for the model as shown in Table 1.

Table 1: Models generated for assessing the crown health using the crown ratio

NAME	MODELS	References
Logistic	$CR = \frac{1}{(1+\exp(-b_0+b_1 MHT+b_2 TSC)}$	Popoola and Adesoye, (2012)
Chapman Richard	$CR = \frac{b_0}{\left(1-exp(1+b_1 MHT+b_2 TSC)^{\frac{1}{2}}\right)}$	
MOD Logistic	$CR = \frac{b_0}{1-exp^{(1-b_1 CL+b_2 THT)}}$	Oyebade and Onyeoguzoro, (2017)
Exponential	$CR = b_{0+} exp^{(b_1 CL+b_2 THT)}$	
Polynomial	$CR = b_{0+} exp^{(b_1+b_2 CL+b_3 THT)}$	

Where CR = crown ratio, exp = exponential, MHT = Merchantable height (m), TSC = Tree slenderness coefficient, CL= Crown length (m), THT = Tree total height (m) and b_0, b_1, b_2 are the regression parameters

Crown ratio model evaluation and validation

One of the intrinsic parts in model development is evaluation of the model. Evaluation of model are been carried out as to assist in determining the best model that is illustrative of the data collected from the field or the study area. The models generated were evaluated based on graphical and numerical analysis of the residuals and four statistical fit indices were used in evaluating the models.

1. **Coefficient of Determination (R^2):** The R^2 measures the proportion of variation in the dependent variable based on the behavior of the independent variable. R^2 value must be higher for the model to be considered valid. The formula below was used to compute it.

$$R^2 = \frac{SSregression}{SSTotal} \times 100 \ldots\ldots (4)$$

2. **Root Mean Square Error (RMSE):** This is the sum square of the vertical distances between the data point and its corresponding data point on the regression line. The RMSE must be relatively small for the model to be considered valid.

$$\boldsymbol{RMSE} = \sqrt{\frac{\Sigma(Y_i - Y')^2}{n}} \ldots. (5)$$

3. **Bayesian Information Criterion (BIC):** For a model to be considered valid its BIC must be relatively low.

   $$\boldsymbol{BIC = n\ ln\left(\frac{rss}{n}\right) + p\ ln} \ldots (6)$$

4. **Akaike Information Criteria (AIC):** This estimates the amount of information lost by a model thereby estimating the quality of the model. For a model to be considered good fit its AIC value must be relatively low.

   $$\boldsymbol{AIC = n\ ln\left(\frac{rss}{n}\right) + 2p} \ldots\ldots (7)$$

Where SS= Sum square, rss = residual sum square, n = sample size, p = number of model fixed parameters, Y_i = the observed value and Y^i = the theoretical value predicted by the model.

Model Validation

Validating of the model was based on the qualitative assessment of the model outputs compared with the real-world data that are independent of the data used in the model construction. In fitting models in forestry, the data obtained from the field are usually divided into two data sets. The Calibration data set and the Validation data set. The first data set was the calibration data (75%) which was used in fitting the models, and the second data set is the Validation data (25%) kept aside for validating the model was used for this purpose. In forest growth models, it has been reported that fewer data are often used for validation while larger data are being used for fitting the models (Adekunle, 2007; Akindele, 2015; Aghimien *et al.,* 2016, Ige *et al.,* 2019), T-Test was used to test for significant difference between the predicted value of the model fitted and the actual value (Independent data set). Model validation is basically used to show that the model predicted is close enough to independent data and that the decision made based on the fitted are defensible and realistic. Confidence level of 5% was used for statistical significance. A model is considered acceptable when there is no significant different between the observed and the predicted values. A model with the P-value greater than 0.05 (p>0.05) is considered acceptable while models is said to be significant and not acceptable when the P-value is lesser than 0.05 (p<0.05).

Two Sample T-Test equations is given as

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_{X_1X_2} \cdot \sqrt{\frac{2}{n}}} \ldots\ldots\ldots\ldots (8)$$

$$S_{X_1X_2} = \sqrt{\frac{1}{2}\left(S_{X_1}^2 + S_{X_2}^2\right)} \ldots. (9)$$

Where:

$\bar{X}_1$ = Means for prediction model
$\bar{X}_2$ = Mean of the data set kept aside for validation
$S_{X1\&X2}$ = Pooled standard deviation

RESULT

General Stand Growth Estimate

The total numbers of tree (≥10cm dbh) measured in the forest was 389 stem ha^{-1}. Table 2 revealed the statistical summary of the tree growth characteristics for this study. The diameter at breast height (DBH) for the study area ranges from 10cm to 170cm with mean value of 25.12±1.03 cm. The tree height ranges from 7.70m to 38.10m with a mean value of 18.55±0. 32m. The numbers of tree per hectare in a sample plot ranges from 96 to 704 with a mean value of 442. The mean volume and basal area were 1.04±0.14m^3 and 0.08±0.01 m^2, respectively with minimum and maximum values of 0.003 and 24.676 m^3; and 0.007 and 2.270 m^2. The crown diameter had a mean value of 5.89±0.08m with respective minimum and maximum values of 3 and 13.7m. This showed that the trees are relatively growing well in the study area. The crown length and crown ratio had respective mean value of 2.97±0.06 and 0.17±0.004 with their minimum and maximum values of 1 and 7.8m; and 0.05and 0.51. The slenderness coefficient value had a mean value of 93.14±1.90 with a minimum and maximum slenderness coefficient of 22 and 225%. The quadratic mean diameter was 31.49±0.41 with the minimum value for a plot of 18.05 and maximum value of 52.66. Table 3 shows the linear correlation coefficient for the whole stand growth variable and other derived variables. There were no significant relationships between the crown diameter and other growth variables such as merchantable height, tree total height, basal area, slenderness coefficient, numbers of tree per hectare, volume, crown length and the crown ratio. Relationship between numbers of tree per hectare (N/ha) and other growth variables was found to be non-significant at alpha level of 0.05. However, diameter at breast height has a significant relationship with all growth variables except in the case of numbers of tree per hectare (N/ha) which the relationship was found to be a non-significant negative correlation coefficient. There is no significant correlation between the stem volume with crown diameter and numbers of tree per hectare.

Table 2: Statistical summary of the tree growth characteristics

Stand Growth Variable	Mean	Count	MIN	MAX
DBH (cm)	25.123 ± 1.026	389	10	170
THT (m)	18.548 ± 0.324	389	7.7	38.1
MHT (m)	15.038 ± 0.336	389	3.8	36
VOL (m^3)	1.035 ± 0.136	389	0.003	24.676
BAL (m^2)	0.083 ± 0.010	389	0.007	2.270
CL (m)	2.9688 ± 0.059	389	1	7.8
CR (m)	0.174 ± 0.004	389	0.051	0.506
SC	93 .140 ± 1.896	389	22	225
N/ha	442	389	96	704
Dq(cm)	31.488 ± 0.406	389	18.047	52.655
CD(m)	5.894 ± 0.083	389	3	13.7

Where: DBH= Diameter at Breast Height, THT= Tree Total Height, MHT= Merchantable Height, VOL= Volume, BAL= Basal Area, CL= Crown Length, CR= Crown Ratio, SC= slenderness Coefficient, N/ha= Numbers of Tree per Hectare, Dq= Quadratic Mean Diameter, CD= Crown Diameter

Tree Crown Correlation Analysis

Correlation is a statistic that measures the degree to which two variables move in relation to each other. The two variables are response variables and independent variable. Table 4 shows the correlation matrix for the growth variable used for fitting the tree crown models. The correlation matrix presented reveals that tree crown ratio decreased with increasing tree size and competition. The correlation between the crown ratios with tree height (THT), merchantable height (MHT) and slenderness coefficient shows a negative correlation. However, the values of the correlation coefficient for crown ratio with MHT and THT where significant at alpha level of 0.05, while the relationship of crown ratio with slenderness coefficient was not significant. The crown length also had a significant positive correlation with tree height, merchantable height and crown ratio. The summary statistics of the tree growth characteristic shown in table 2 indicates that the crown ration has a mean value of 0.174 ± 0.004 with a minimum and maximum value of 0.051 and 0.506 respectively. The crown diameter had a mean value of 5.89±0.083 with a minimum and maximum value of 3 and 13.7, respectively. The crown length had a mean value of 2.97±0.06 with minimum and maximum value of 1 and 7.8m, respectively.

Table 3: Correlation Matrix for the whole stand growth variable

	DBH	CD	MHT	THT	BA	SC	N/ha	SV	CL	CR
DBH	1									
CD	-0.095*	1								
MHT	0.583*	-0.060	1							
THT	0.595*	-0.069	0.985*	1						
BA	0.926*	-0.074	0.429*	0.441*	1					
SC	-0.639*	0.091	-0.043	-0.044	-0.475*	1				
N/ha	-0.022	0.020	0.089	0.083	-0.020	0.105	1			
SV	0.884*	0.035	0.503*	0.518*	0.909*	-0.436*	-0.048	1		
CL	0.151*	0.061	0.055	0.225*	0.132*	-0.014	-0.019	0.163*	1	
CR	-0.265*	0.029	-0.663*	-0.538*	-0.174*	-0.045	-0.167*	-0.199*	0.629*	1

Where DBH= Diameter at Breast Height (cm), CD= Crown Diameter (m), MHT= Merchantable Height (m), THT= Tree Total Height (m), BA= Basal area (m^2), SC = Slenderness coefficient, N/ha = Numbers of tree per hectare (m^2), SV= Stem Volume (m^3), CL= Crown Length (m) and CR= Crown Ratio (m)

Table 4: Correlation matrix for growth variable used for fitting crown model

	THT	MHT	SC	CD	CR	CL
THt	1					
MHT	0.985*	1				
SC	-0.044*	-0.043	1			
CD	-0.069	0.272	0.091	1		
CR	-0.538*	-0.663*	-0.045	0.029	1	
CL	0.225*	0.055*	-0.014	0.061	0.629*	1

**there is a significant different, THT= Tree Total Height (m), MHT= Merchantable Height (m), SC= Slenderness coefficient, CR= Crown Ratio (m), CL= Crown Length (m) and CD= Crown Diameter (m)*

Crown Ratio Model Fitted and Evaluation

Five selected models for estimating crown ratio for the study area are shown in Table 5 with their corresponding parameter estimates. The result of the fit indices (Table 6) revealed that the best model for predicting the crown ratio is the Modified exponential model which had the least RMSE, AIC, BIC and highest coefficient of determination (R^2) values of 0.02688, - 1278.412, -1263.705 and 0.906, respectively. The poorest performed model was Chapman Richard with RMSE, AIC, BIC and R^2 values of 0.06854, -731.674, -716.967 and 0.389, respectively. Figures 3 to 7 depict the residual analysis for all the models evaluated in the study. This was done in order to ascertain the model accuracy with the assumption of homoscedasticity (to check if the error analysis is independent and normally distributed with zero mean and constant variance). Modified Exponential and polynomial models met all the assumption of homoscedasticity, thus indicating the error variance is constant across the predicted crown ratio and the estimated residual for crown, frequency and normal quintiles residual for Modified exponential and polynomial models had constant error variance distributed both in the negative and positive region of the X-axis (distributed within the range of -0.15 to 0.15) while the histogram was also within the range of -0.15 to 0.15 in the negative and positive region of the Y-axis. Logistic, Chapman Richard and Exponential had a positive skewness in the X-axis of the estimated residual, frequency and normal quintiles residual as shown in Figures 3, 4 and 4.

Table 5: Model Evaluated Parameters

Model Name	Fitted Models	RMSE	AIC	BIC	R^2
Logistic	$CR = \frac{1}{(1+\exp(0.3755+0.0082MHT-0.0000739TSC)}$	0.06426	-769.2921	-754.5851	0.463
Chapman R	$CR = \frac{1.680}{\left(1-exp(1+0.00573MHT+0.000125TSC)^{\frac{1}{2}}\right)}$	0.06854	-731.674	-716.967	0.389
Exponential	$CR = -0.952549 + exp^{(0.040729CL-0.035035\ /TSC)}$	0.06256	-784.9017	-770.1947	0.4910
Polynomial	$CR - 0.92332 + exp^{(0.099373+0.049655CL-0.008424THT)}$	0.02692	-1276.536	-1258.152	0.906
Modified Exponential	$CR = -0.81745 + exp^{(0.05451CL-0.0934THT)}$	0.02688	-1278.412	-1263.705	0.906

Where CR= Crown ratio, MHT= Merchantable height, TSC= Tree slenderness coefficient, THT= Tree total height and exp = exponential

Table 6: Fit Indices

Model Name	Model Function	b_0	b_1	b_2	b_3
Logistic	$CR = \frac{1}{(1 + \exp\,(b_0 + b_1 MHT + b_2 TSC)}$	-0.3755	0.0082	-0.0000739	
Chapman	$CR = \frac{b_0}{\left(1 - exp(1 + b_1 MHT + b_2)^{\frac{1}{2}}\right)}$	1.680	0.00573	0.000125	
Exponential	$CR = b_0 + exp^{(b_1 CL + b_2/TSC)}$	-0.95255	0.040729	-0.035035	
Polynomial	$CR = b_0 + exp^{(b_1 + b_2 CL + b_3 THT)}$	-0.92332	0.099373	0.049655	-0.008424
Modified Exponential	$CR = b_0 + exp^{(b_1 CL + b_2 THT)}$	-0.81745	0.05451	-0.00934	

Where: b_0 = intercept, b_1, b_2 and b_3 are the regression slope coefficient.

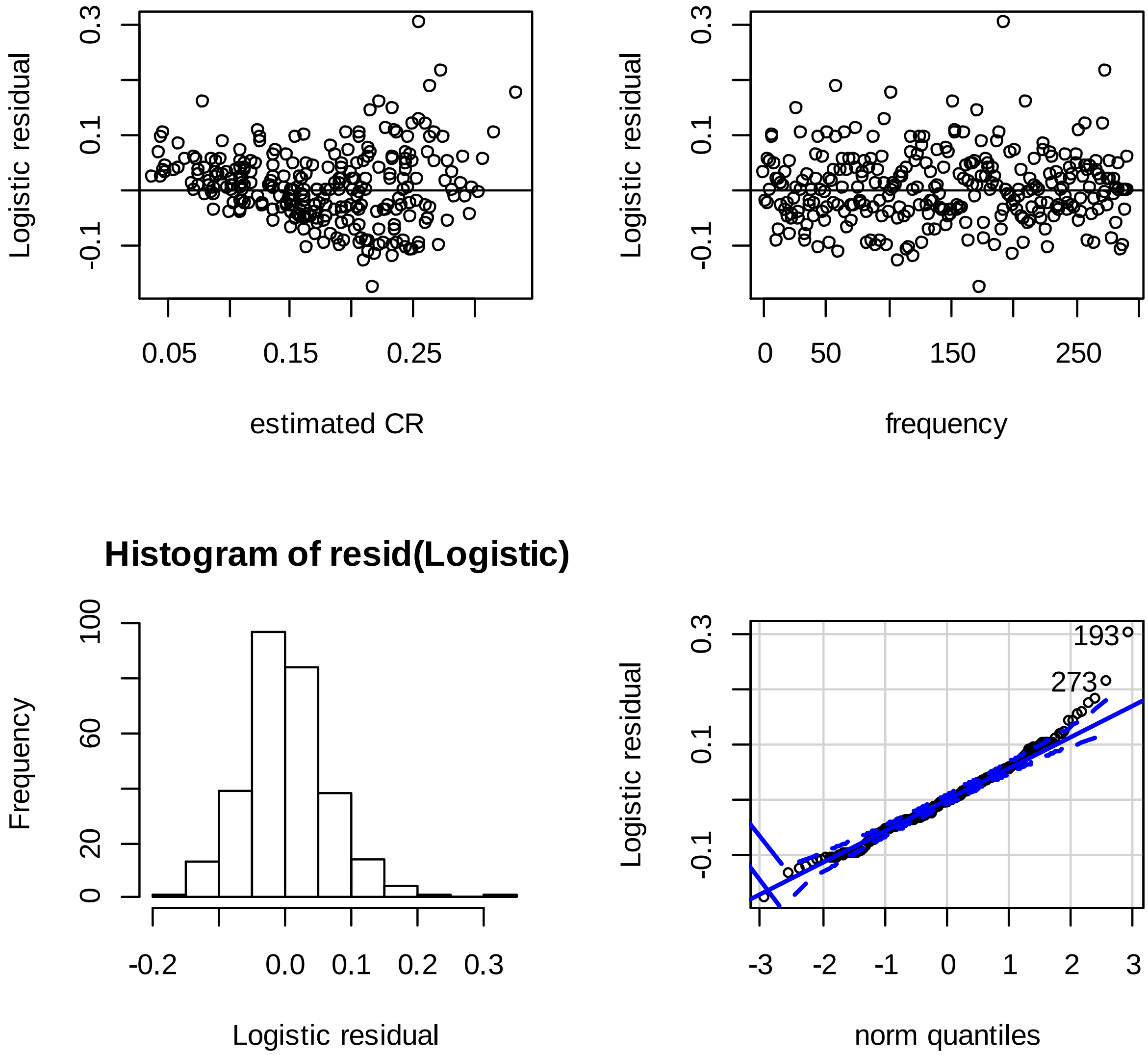

Figure 3: Residual plot of the Logistic Model

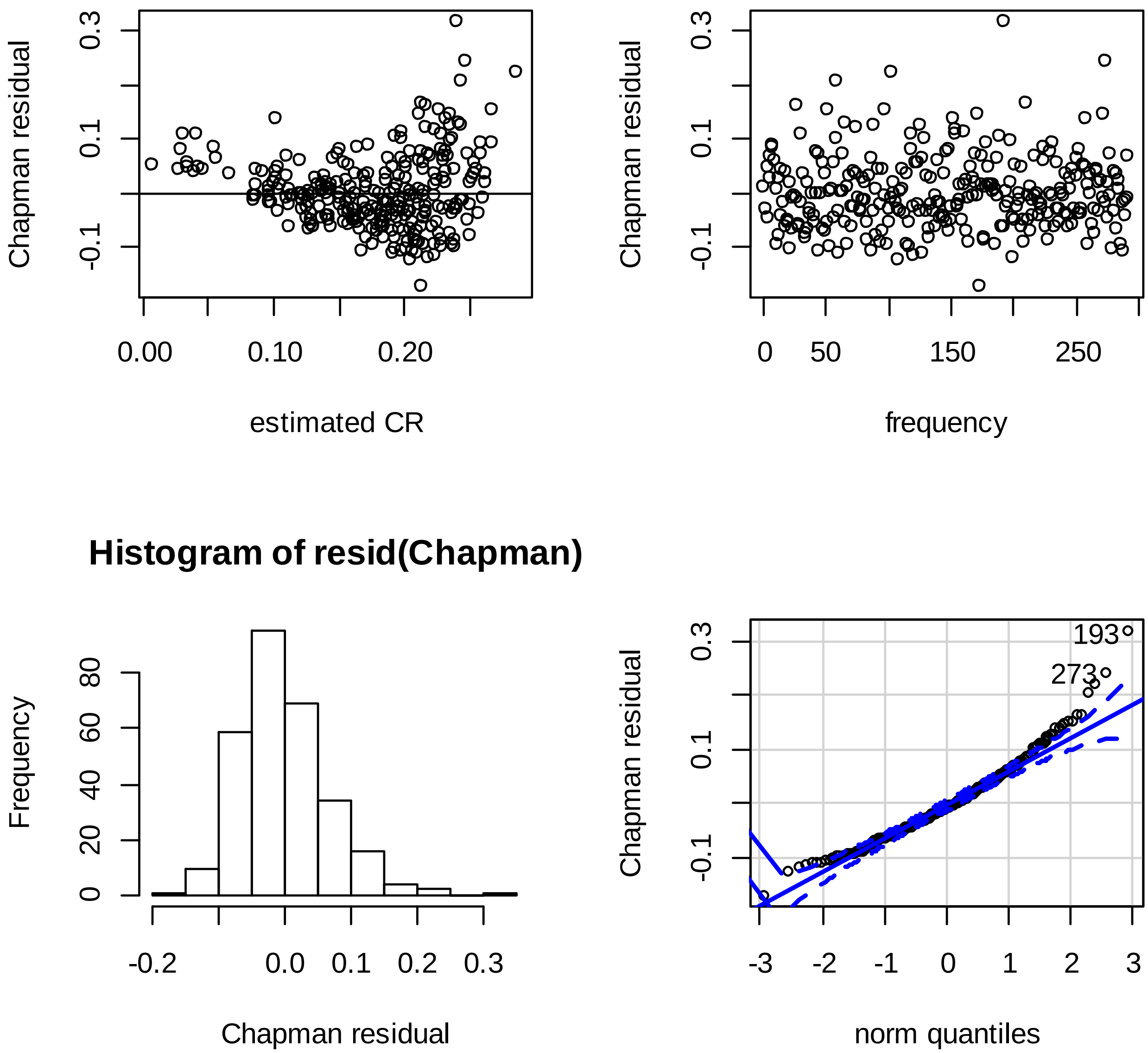

Figure 4: Residual plot of the Chapman Richard Model

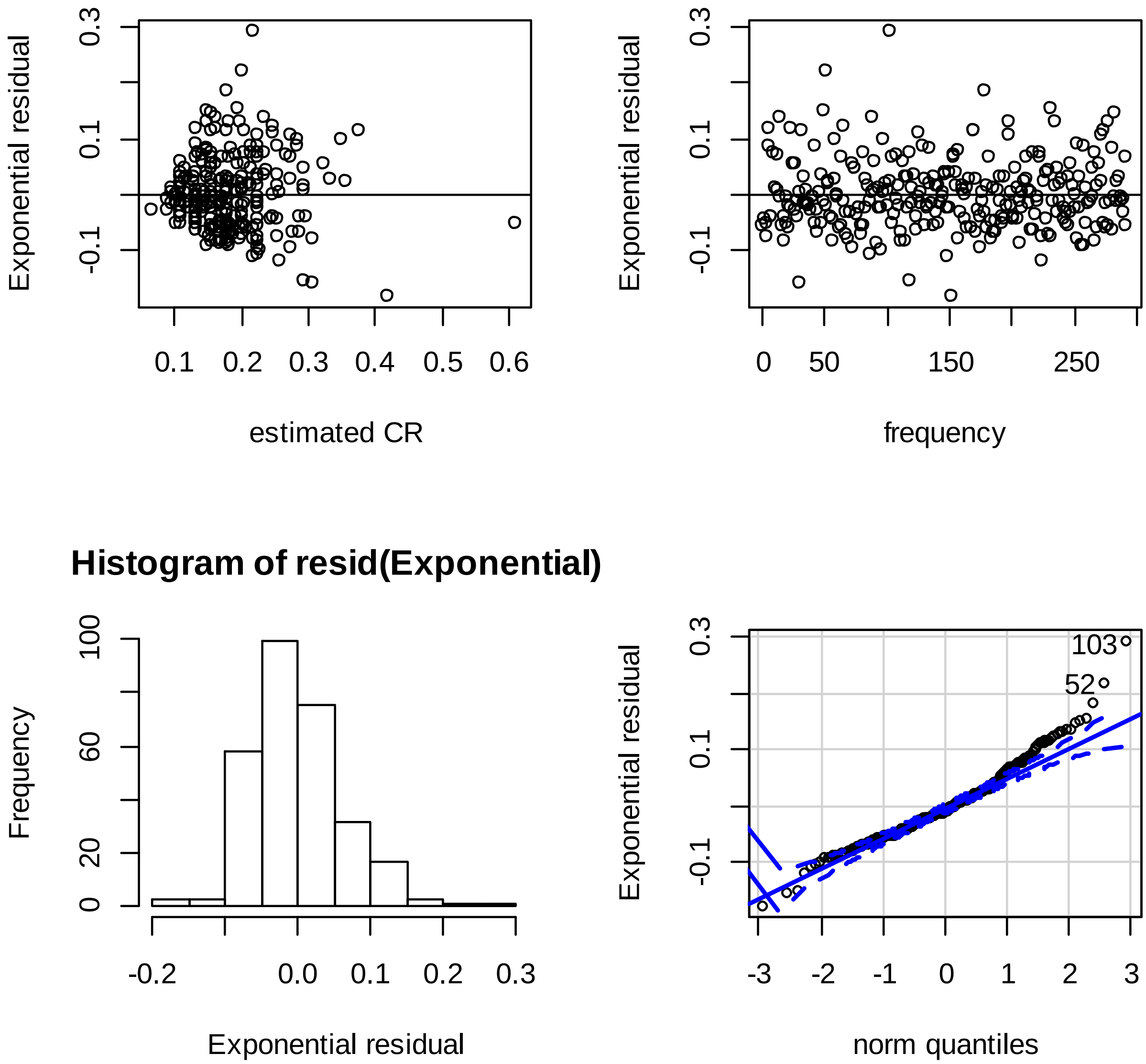

Figure 5: Residual plot of the Exponential Model

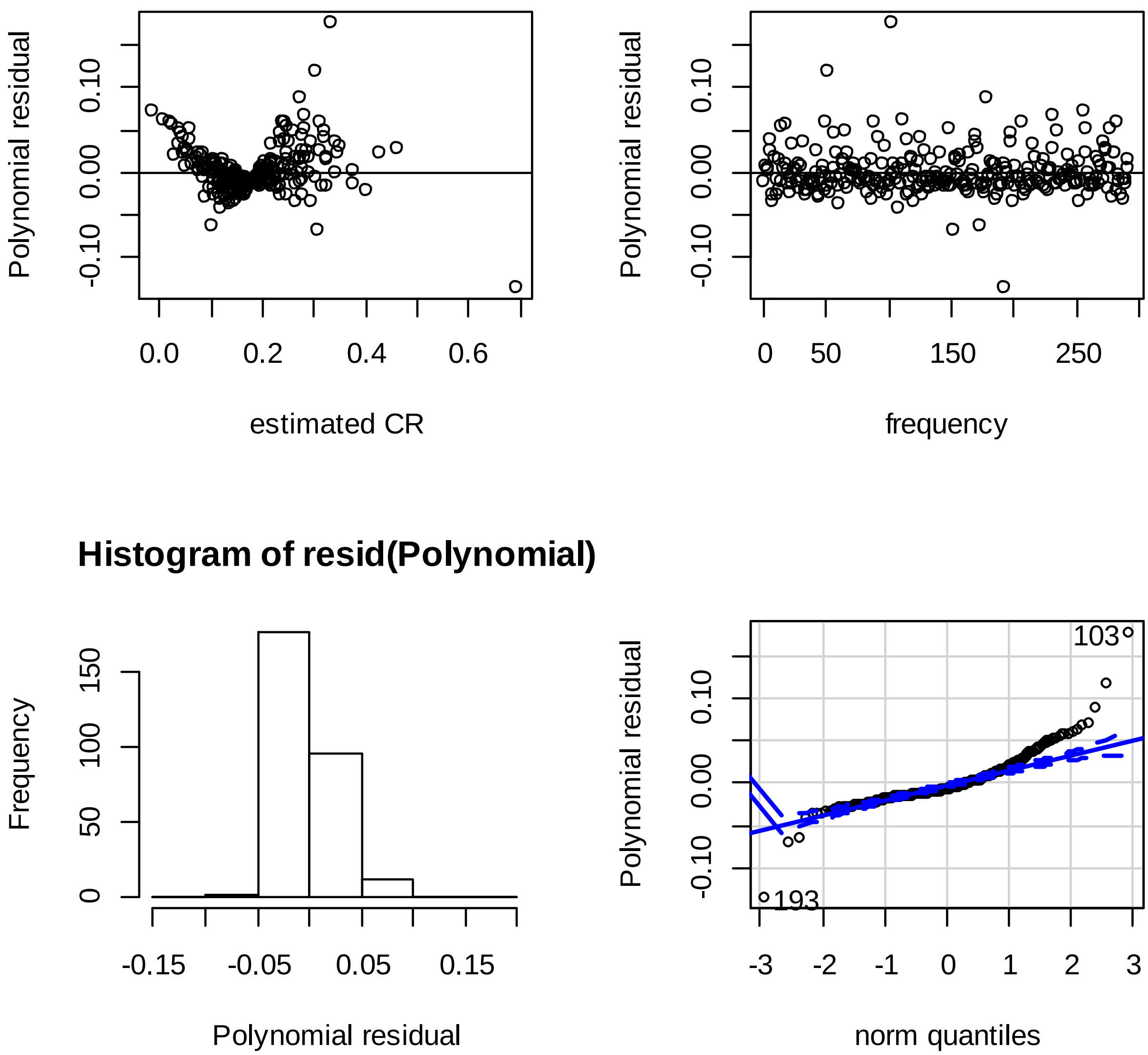

Figure 6: Residual plot for Polynomial Model

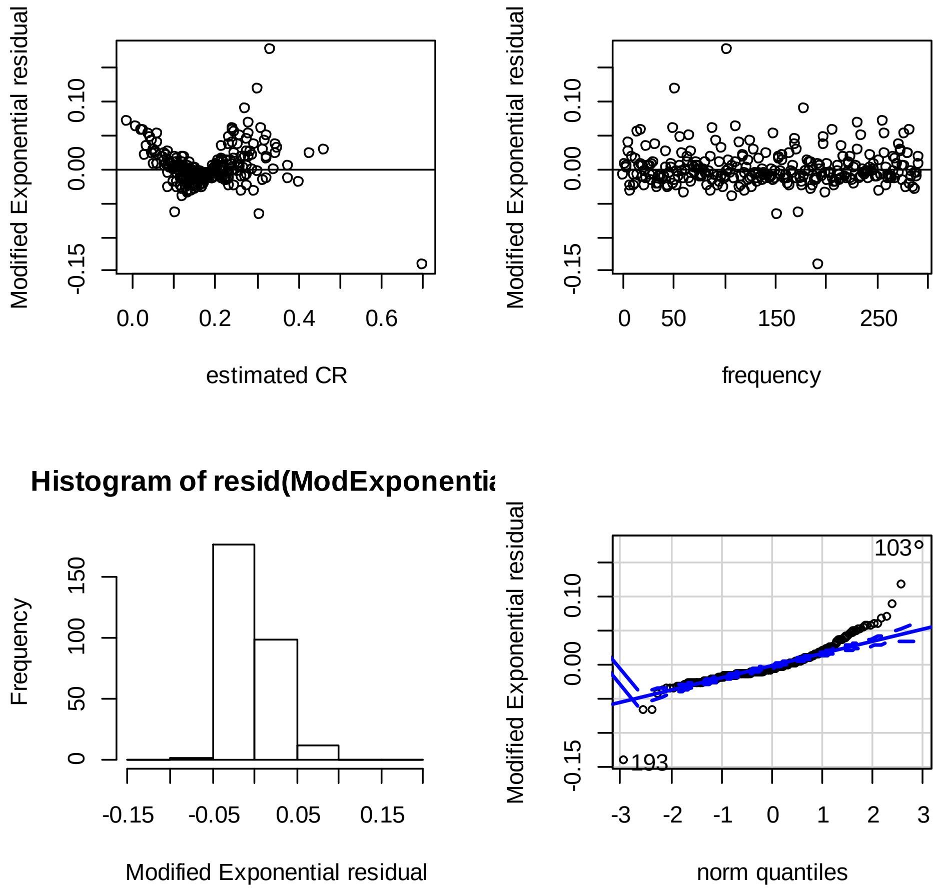

Figure 7: Residual plot for Modified Exponential Model

Model Validation for Crown Ratio

Model output was compared with the observed value (Independent data). However, the results of the model validation for all the crown models generated are presented in Table 7. There was no significant different between the observed and predicted values for all the models indicating values greater than the alpha level of 0.05. However, assumption of normality test carried out on all the models using Shapiro Wilk test was not met by the entire model. They all have p-value lesser than 0.05 which means that the data significantly deviated from a normal distribution. But the predicted value was however compared with the observed value using two sample t-test they have no significant difference between the observed mean and the predicted mean with their P-value greater than the alpha level of 0.05 as shown in table 7.

Table 7: Crown ratio models validation

Models	**Mean predicted value**	**Mean Observed value**	**Validation Predicted vs. Observed T-Test**		**Normality Test Shapiro Wilk Test**
		T-Value		P-Value	P-Value
Logistic	0.1676289	0.1640021	0.3471	0.7289	0.0001104
Chapman Richard	0.1676289	0.1696688	-0.20456	0.8382	$5.511x10^{-07}$
Exponential	0.1676289	0.1773647	-0.97135	0.3327	$1.17x10^{-06}$
Polynomial	0.1676289	0.1673770	0.02226	0.9823	$3.418x10^{-16}$
Modified Exponential	0.1676289	0.1673226	0.027109	0.9784	$3.565x10^{-16}$
Calibration Data = 292			**Validation = 97**		

DISCUSSION

Tree crown ratio model were developed for the study area, which will be useful in assessing the tree crown condition of the forest. Crown ratio model was generated following Popoola and Adesoye–(2012), Oyebade and Onyeoguzoro (2017). The tree crown condition is known to be one of the main and effective ways of describing the tree productivity and health of a forest stand Van Laar and Akca (2007). The correlation matrix between crown ratio with tree total height (THT), merchantable height (MHT) and slenderness coefficient (TSC) shows a negative correlation for this study which also agrees with the study carried out by Popoola and Adesoye (2012) on crown ratio models for *Tectona grandis* stands in Osho Forest reserve, Oyo State, Nigeria. The Crown ratio and the Crown length have a significant higher correlation value. The negative relationship is often attributed to decrease in crown ratio with growing tree size and competition which also indicate that tall trees that are slender do have a lower crown ratio value (Popoola and Adesoye, 2012).

But this was in contrast with the findings of Oyebade and Onyeoguzoro (2017) where he observed that the correlation between crown ratio and the THT, MHT, TSC and DBH were positive with a low value for tree crown ratio model for *Hevea brasiliensis* plantation in Edo State, Nigeria. This could be as a result of the uniformity in the tree size as compare to a natural stand. The Non-least square regression method was used in fitting the model. The model fitted for predicting the crown ratios are logistics, Chapman Richard, Exponential, Polynomial and Modified Exponential. Modified Exponential and polynomial models met all the assumption of homoscedasticity, thus indicating the error variance is constant across the predicted crown ratio. Thus, a desirable trait for a good model must have its residual randomly and evenly distributed with zero mean and constant variance which modified exponential and polynomial model possessed. This was also observed in the research work of Popoola and Adesoye (2012) in their study that exponential model met the assumption of homoscedasticity and was recommended for crown ratio prediction. However, Modified exponential function and Polynomial function are recommended for crown ratio prediction in the study area. Modified had the least RMSE, AIC, BIC and high coefficient of determination (R^2) value of 0.02688, - 1278.412, -1263.705 and 0.906, respectively while Polynomial had RMSE, AIC, BIC and R^2 values of 0.02692, -1276.536 and -1258.152 and 0.906, respectively.

CONCLUSIONS AND RECOMMENDATION

The study has provided quantitative information on tree crown ratio models for International Institute of Tropical Agriculture Ibadan, Nigeria. The result revealed that the best adjudged model for crown ratio in the study area is modified exponential function which is therefore recommended to be used for tree crown ratio modeling and should be considered useful tool for managing the forest for biodiversity conservation.

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