FITTING LINEAR AND NON-LINEAR VOLUME MODELS IN OKPON RAINFOREST RESERVE OF CROSS RIVER STATE, NIGERIA

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ABSTRACT

This study was aimed at providing the most appropriate linear and non-linear models for effective and efficient management of Okpon tropical rainforest reserve of Cross River State, Nigeria. Systematic line transect was used to lay sample plots. Two transects of 1500m in length with a distance of at least 500m between the two parallel transects were used for this study. Sample plots of 50m X 50m in size were laid in alternate along each transect at 100m interval and thus, summing up to 10 sample plots per 1500m transect and a total of 20 sample plots in the study area. A total of 1100 individual tree species spread across 65 species belonging to 21 different tree families were measured for diameter at breast height, diameters at the base, middle and top and tree total height. The mean diameter at breast height and total height of 28.8cm and 18.6m were obtained. Mean basal area of 50.29 m^2 ha^{-1} was obtained with a mean volume of 271.249 m^3 ha^{-1}. SPSS software was used for the linear regression models while Curve Expert software was used for the non-linear regression models. Simple linear and non-linear models were developed for the Okpon Forest Reserve. To further test the validity, accuracy and consistency of the simple linear model, validation tests carried out revealed very lower bias percentage and also, there were no significant differences between the observed and the predicted values, which further imply that the linear model is fit for tree volume estimation in the Okpon Forest Reserve. Furthermore, non-linear model was also developed; however, Gompertz Relation was the most flexible for volume estimation based on the assessment criteria (AIC and standard error) in the study area. Thus, the models developed are judged fit for effective and efficient management of the Okpon Forest Reserve.

Keywords: Non-linear, Models, Systematic sampling, Transect and Sustainable management.

INTRODUCTION

According to Turner (2001), the tropical rain forest is the most diverse of all terrestrial ecosystems, containing more plant and animal species than any other biome. In spite of this diversity, most species are locally endemic or rare and patchily distributed (Richards, 1996). Thus, the overall timber value per unit area is generally low, thereby necessitating logging activities over large areas in order to meet the ever-increasing demand. The FAO (1999) estimated that tropical countries are losing 127,300 km2 of forest annually. In view of the great value of the tropical rain forest and the grave consequences of losing it to unregulated logging activities and over exploitation, it has become the focus of increasing public attention in recent years.

Sustainable forest management requires estimates of growing stock. Such information guides forest managers in timber valuation as well as in allocation of forest areas for harvest. For timber production, an estimate of growing stock is often expressed in terms of timber volume, which can be estimated from easily measurable tree dimensions. The most common procedure is to use volume equations based on relationships between volume and variables such as diameter and height. According to Avery and Burkhart (2002), volume equations are used to estimate average content of standing trees of various sizes and species. The reliability of volume estimates depends on the range and extent of the available sample data, and how well volume equations fit this sample data (Bassey and Ajayi, 2021).

The pronounced heterogeneity in species composition and structure even within small areas constitutes a major challenge in development of volume functions for natural tropical forests. Furthermore, some tree variables, including volume is extremely time consuming to measure in field inventories, and need to be predicted by using statistical prediction models prepared in surveys separate from those of operational forest inventories. However, in many cases, there are no models available for predicting different volume components that are country specific and based on data covering the entire target area of forest inventory.

Foresters need to know every detail about the forest they are managing in terms of location, size, quantity and quality of forest resources available and how these resources are changing over time. This information can be obtained through proper resource modeling. Vanclay (1994), defined models as abstractions of the natural dynamics of a forest stand, which may encompasses growth, mortality and other changes in stand composition and structure. Models are used for operational and strategic planning in nations that own and manage forest lands. Modeling is also good for decision making regarding buying, selling, and trading in forest resources. Therefore, forest models can be used as very successful research and management tools. The development of effective and accurate models to predict forest volume and biomass is essential for forest managers and planners. It is to this effect that is research aimed at fitting linear and non-linear models for models for Okpon Forest Reserve, Cross River State, Nigeria.

METHODOLOGY

Study Area

The research was conducted in the Okpon River Forest. Okpon River Forest Reserve is located within Obubra, Etung and Yakurr Local Government Areas in Cross River State, Nigeria (Latitudes $5^{o}40^{1}30^{11}$ and $5^{o}57^{1}30^{11}$ N and Longitudes $8^{o}12^{1}00^{11}$ and $8^{o}32^{1}00^{11}$ E). The reserve has a total area of thirty-one thousand, three hundred hectares (31,300 Ha.) (NASDRA and FAO, 2014). The elevation of the study areas ranged between 14 m and 87 m above mean sea level. The study area has a moist tropical maritime climate, with high rainfall concentrated during monsoon period from June to September and high temperature. The mean annual rainfall ranges from 2,500mm in January to 4,000mm in August. The rain is fairly distributed through-out the months of April to October. Mean annual temperature range from 27.6^{0} C in August to 33.1^{0} C in February. The Strong winds usually accompany the onset of dry season, which is caused by hot and dry North East wind. The mean relative humidity ranges from 71% in February to 90% in August (Ajayi, 2006).

Sampling Procedure and Data Collection

Systematic line transect was employed in the laying of plots. Two transects of 1500m in length with a distance of at least 500m between the two parallel transects were used in each of the study sites. Sample plots of 50m X 50m in size were laid in alternate along each transect at 100m interval and thus summing up to 10 sample plots per 1500m transect and a total of 20 sample plots in the forest reserves-figure 1.

In each plot, all living trees with dbh $\geq$10cm were identified and measured. Spiegel relaskop was used for individual tree DBH and diameters (diameter at the base, diameter at the middle and diameter at the top) and tree height measurement.

For trees growing on a slope, the dbh was measured from the uphill side. Buttresses were considered to be non-commercial. So, when buttresses extending more than 1.30 m above ground surface were encountered, the equivalent of dbh was measured at a height of 20 cm above the upper limit of the buttresses. When knots or localized deformations occurred at breast-height point, a more representative dbh point either above or below the breast-height point was chosen (Adekunle *et al.*, 2010).

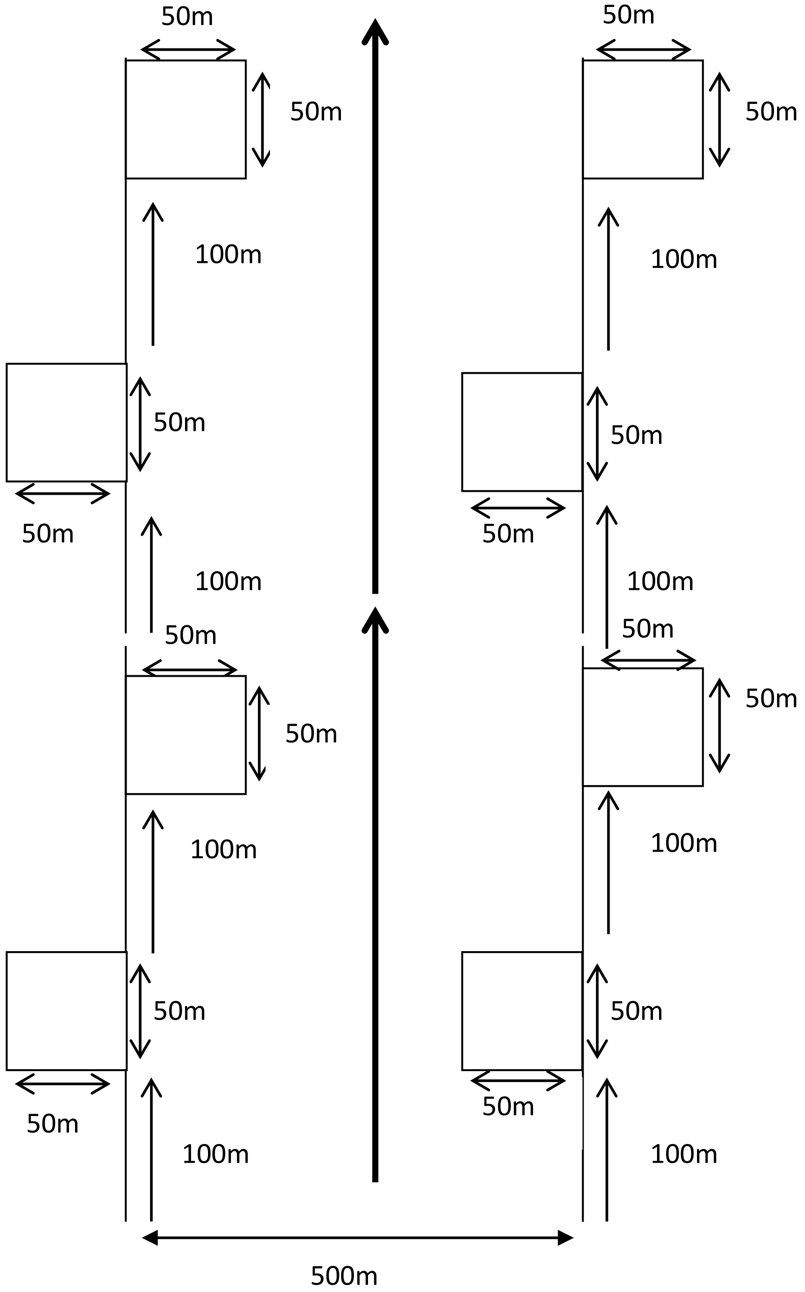

Figure 3: Plot layout with systematic line transects sampling technique.

Data Analysis
Basal Area Estimation
The diameter at breast height was used to calculate the basal area.

$$Basal\ Area\ (BA) = \frac{\pi D^2}{4} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..1$$

Where: D = diameter at breast height (m), π = 3.14 and BA = Basal Area (m^2).

The total Basal Area (BA) for each plot was obtained by adding all trees basal area in the plot while mean basal area for the plot was calculated with the formula:

$$\overline{BA_p} = \frac{\Sigma BA}{n} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..\dots\dots.2$$

where; $\overline{\mathrm{BA_p}}$ = Mean basal area per plot ann = Toatal number all possible samplot plot

Stem Volume Estimation

Individual tree volume was calculated using the Newton's formula of Husch *et al.*, (2003):

$$V = \frac{h}{6}[A_b + 4A_m + A_t] \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..\dots\dots.3$$

Where: V= Volume (m^3), A_b = Basal area at the base (m^2), A_m = Mid basal area (m^2) and A_t = Basal area at the top (m^2)

The plot volumes was obtained by adding the volume of all the trees in the plot while mean plot volume was obtained by dividing the total plot volume by number of sample plots. The volume of trees per hectare (V_{ha}) was subsequently estimated by multiplying the mean per plot by the number of sampling units in a hectare (Adekunle, 2007).

Linear Regression Volume Models

Regarding linear volume model generation, the field inventory data was divided into two. The first set was used for model calibration which comprised of 70% of the tree data while the second set was used for model validation which comprised of 30% of the tree data set. The individual tree growth variables across the sample plots were independent variables. The generalized allometric equation for mathematics and science and the linear regression models that followed the general Schumacher (1939) yield models were used. The Schumacher model is of the form:

$$Y = f(A, SQ, SD)$$

Where: Y = function of yield e.g. volume, A = age, SQ = function of site quality e.g. site index, height, SD = function of stand density e.g. diameter at breast height, basal area.

So, the stand linear regression models adopted in this study followed the Schumacher functions and are represented in equations 3.5-3.8:

Simple Linear model:	$V = b_0 + b_1x$	4
Binomial model:	$V = b_0 + b_1x^2$	5
Logarithm transformed Model:	$LnV = b_0 + b_1Lnx$	6
Polynomial Models:	$V = b_0 + b_1x^2 + b_1x^3 + b_1x^4$	7

Where V = stand volume (m^3ha^{-1}) and X = stand basal area (m^2 ha^{-1})

Criteria for Linear Volume Model Assessment

The linear stand volume models were assessed with the view of recommending those with good fit for management and prediction of the Reserves. Therefore, the following criteria were used:

Coefficient of Determination (R^2): This is the measure of the proportion of variation in the dependent variable that is explained by the behavior of the independent variable (Thomas, 1977). For the model to be accepted, the R^2 value must be high (>50%) (Aigbe *et al*, 2013).

$$R^2 = \frac{Regression\ sum\ of\ square}{Total\ sum\ of\ square} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 8$$

Standard Error of Estimate (SEE): This is also referred to as the standard deviation or residual of the error variance of the estimate. It measures the spread of data and is a good indicator of precision. The value must be small. It is the square root of the average squared error of prediction and it is used as a measure of the accuracy of prediction. SEE is expressed as:

$$SSE = \sqrt{\frac{\Sigma[y_i - \bar{y_i}]^2}{n-p}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .9$$

Where y_i = Actual tree volume

$\bar{y_i}$ = Predicted tree volume

n = Number of observations

p = Number of parameters in the volume models.

Adjusted Coefficient of Determination $[R_a^2]$

$$R_a^2 = 1\frac{\sum_{i=1}^{N}[W_i - \widehat{W}_i]^2}{\sum_{i=1}^{N}[W_i - \overline{W}]^2}\frac{N-1}{N-p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots ..10$$

Where; W_i= value of the *i*th observed stand volume

$\widehat{W}_i$=*i*th stand volume prediction from the model fit to all the data (sample size *N*)

$\overline{W}_i$= the average value of the stand volume

N = Sample size

Non-linear regression volume models

The non-linear regressions for individual tree models were generated using Curve Expert Professional software. The models and the model functions are as represented in Table 1 below:

Table 1: Non Linear Model Volume functions

Model	Model Function
Logistic Power	$V = \frac{a}{\left(1 + \left(x/_b\right)^2 c\right)}$
Gompertz Relation	$V = a * exp\big(-exp(b - c * x)\big)$
MMF	$V = \frac{(a * b + c * x^d)}{b + x^d}$
Weibull	$V = a - b * exp(-c * x^d)$
Logistic	$V = \frac{a}{(1 + \mathrm{b} * e^{(-cx)})}$
Ratkowsky model	$V = \frac{a}{(1 + \exp(b - c * x))}$

a, b, c and d are parameters to be estimated, V is the volume in (m^3), x is the Dbh (cm) while exp. is the exponential.

Criteria for Non-linear Volume and Biomass Models Selection

All the non-linear models will be assessed with the Standard error of estimate (SEE) and Akaike Information Criterion AIC as thus:

Standard Error of Estimate (SEE):
It is the square root of the average squared error of prediction and it is used as a measure of the accuracy of prediction. SEE is expressed as:

$$SSE = \sqrt{\frac{\Sigma[y_i - \bar{y_i}]^2}{n-p}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.25$$

Where y_i = Actual tree volume
$\bar{y_i}$ = Predicted tree volume
n = Number of observations
p = Number of parameters in the volume models.

The value must be small to be judged a good model.

Akaike's Information Criteria (AIC)
The idea of AIC (Akaike, 1973) is to select the model that minimizes the negative likelihood penalized by the number of parameters as specified in the equation below:

$$AIC = 2Logp\ (L) + p \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.26$$

Where *L* refers to the likelihood under the fitted model and *p* is the number of parameters in the model.

Validation of Non-linear Volume Selected Models
For non-linear individual tree models, models with good fit, the intercept must be close to 0 and the slope is close to 1, the model must be significant, highly correlated, the coefficient of determination value must be very high and the standard of error of estimate must be small (Onyekwelu and Akindele, 1995; Adekunle *et al*., 2004). The models output was compared with observed values obtained from the field with student t-test and simple linear regression for any significant difference.

The student t-test: This was used to test for any significant difference between the actual values or field values and the predicted values (model output) of the various models generated according to Goulding, (1979).

$$t = \frac{\bar{D}}{SD/\sqrt{n}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.27$$

Where: T= t-statistics
$\bar{D}$= mean of the difference between pairs
SD= standard deviation of the difference between pairs
n= number of paired observation (degree of freedom is n-1)

Percentage Bias Estimation: The absolute percentage difference (% bias) was determined by dividing the difference between volumes obtained with Newton's formula (observed volume) and models output by the same observed volume and multiplied by 100.

$$Bias\ (\%) = \left[\frac{V_0 - V_P}{V_0}\right] X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.28$$

Where:
V_0= Observed Volume
V_p = Predicted volume

The volume must be relatively small for the model to be acceptable for management purpose.

RESULTS

Summary of Characteristics data for Okpon Forest Reserve
Results in table 2 below show that a total of 1100 individual tree species spread across 65 species belonging to 21 different tree families were measured for diameter at breast

height, diameters at the base, middle and top and tree total height. The mean diameter at breast height and total height of 28.8cm and 18.6m were obtained. Mean basal area of 50.29 $m^2 ha^{-1}$ was obtained with a mean volume of 271.249 $m^3 ha^{-1}$.

Table 2: Summary of Characteristics data for Okpon Forest Reserve in Cross River State, Nigeria

S/N	Parameters	Summary	Min.	Max.	Std. Error	Std. Deviation	Skewness	Kurtosis
1	No. of sample plots measured	20	-	-	-	-	-	-
2	No of trees measured	1100	-	-	-	-	-	-
3	Average DBH (cm)	38.47	3.00	193.80	0.7883	26.03	3.11	12.27
4	Average height	18.6	11.40	46.20	0.55	19.14	2.72	6.84
5	Mean basal area ha^{-1}	50.29	32.05	60.25	0.88	30.21	2.53	13.4
6	Mean volume ha^{-1}	271.25	87.23	234.10	0.53	73.51	2.41	7.12

Linear Stand Volume Models Developed for Okpon Rainforest Reserve, Cross River State, Nigeria

The results in Table 3 below show a linear regression analysis used in developing allometric models for estimating forest stand volume in Okpon forest reserve using stand basal area per hectare as predictor variable. The table also shows the regression constants and coefficients, R^2, Root Mean Square Error (RMSE) F-ratio and Adjusted Means Square Error (R_a^2) for logarithmic and non-logarithmic expressions of the dependable variables in the study area. Model 4 was judged fit and best and therefore selected because it has the highest F-ratio value (23.523) and a very low Standard Error of Estimate (-0.038) with R^2 value of 71.2% and R_a^2 of 62.5%. Ranked very closely were models 1 and 2 which are judged to be fit alternative models for the estimation of stand level tree volume for the reserve.

Table 3: Linear Stand Volume Models Developed for Okpon Forest Reserve, Cross River State, Nigeria

S/N	Models	R^2%	R_a^2	F-ratio	SEE	Remark
1	$V = 168.436 + 0.885X$	60.7	58.0	18.961	-0.003	Suitable
2	$V= 248.602 -4.227X -0.079X^2$	63.2	57.48	19.381	.0106	Suitable
3	$LnV = 4.825 + 0.131LnX$	45.0	42.84	0.949	-0.018	Unsuitable
4	$V = 222.913 -1.439X -33.387X^2 -34.695X^3 + 1.654E\text{-}005X^4$	71.2	62.5	23.523	-0.038	Selected

$V = 222.913-1.439X -33.387X^2 -34.695X^3 + 1.654E\text{-}005X^4$

Validation of Linear Volume Models Developed for Okpon Rainforest Reserve, Cross River State, Nigeria

Results in Table 4 show the residual analysis for stand volume model validation. Thirty percent (30%) of the sampled plot was used for volume model validation. Paired T-test was used to validate the model by comparing the observed stand volume (volume using Husch *et al.*, (2003)) and predicted stand volume (volume obtained using the developed model) as presented in Table 4. The allometric equation selected in the forest reserve recorded non-significant difference (P>0.05) with the observed volume computed from the field. Again, with estimated bias as low as 0.59%, was recorded for Okpon Forest Reserve. Therefore, by the reason of the low bias percentages and the non-significance difference recorded for each of the selected model, it implies that the model is judged good and fit for stand-level volume estimation and prediction in in the forest reserve.

Table 5: Validation of Okpon Forest Reserve Linear Stand Volume Model

S/N	Basal Area (M^2ha^{-1})	Observed Volume (M^3ha^{-1})	Predicted Volume (M^3ha^{-1})	Residuals (M^3ha^{-1})
1	24.1806	189.5652	186.6584	2.9068
2	25.2441	198.1707	193.7341	4.4366
3	22.5217	171.5307	162.5385	8.9922
4	17.3217	154.5418	153.7550	0.7868
5	21.3450	184.8235	182.8451	1.9784
6	18.7016	160.9210	157.6487	3.2723
7	17.5412	153.4637	152.7295	0.7342
8	20.1875	185.1046	187.7352	-2.6306
9	15.8361	152.3482	150.2377	2.1105
10	22.1806	160.7035	170.4761	-9.7726
11	21.8764	151.4573	150.5302	0.9271
12	16.9748	140.5126	145.7342	-5.2216
13	15.5071	139.9542	137.6596	2.2946
14	20.7186	170.3184	172.8021	-2.4837
15	18.4966	145.3428	140.6212	4.7216
16	21.5712	190.1137	178.9201	11.1936
17	22.6201	160.5390	160.6452	-0.1062
18	17.8442	156.7874	160.7382	-3.9508
19	15.5554	148.3870	145.7456	2.6414
20	16.9466	152.0752	155.4388	-3.3636
Total		3266.661	3247.194	54.980

T-calculated = 0.963

T-tabulated = 0.911

Bias = 19.46/3266.661 x100 therefore, Bias= 0.59%

Non-Linear Volume Models and their Assessment Criteria for Okpon Rainforest Reserve of Cross River State, Nigeria

The non-linear models considered were Logistics, Gompertz Relation, Logistic Power, Ratkowsky models, Richards, MMF, and Weibull models and were determined to be good models in describing diameter-volume relationship of trees in study area. The results in Table 5 show the best models for non-linear models generated for the stand level volume estimation in the Okpon rainforest reserve of Cross River State. Logistic model was best fit model and very closely followed by Ratkowsky model and Logistic Power, Gompertz Relation, Weibull and MMF models respectively. However, recommendation was done based on the model with the lowest AIC and standard error values.

However, Figure 1 shows the best non-linear volume models for the reserve. Figure 1 plotted for the non-linear volume model indicated an even spread of residuals above and below the zero line with no systematic trend. Similarly, in order to validate the individual tree volume, Figure 2 is the residual plots of the selected three best nonlinear volume models. It indicates an even spread of above and below the zero line with no systematic trend implying that the selected model is fit for tree volume estimations.

Non-Linear Stand Level Volume Models and their Assessment Criteria for Okpon Tropical Forest Reserve of Cross River State, Nigeria

Forest Reserves	Models	Parameters Estimate				AIC	Std Error
		A	B	C	D		
Ukpon	Gompertz Relation	28.10	2.81	0.09		1989.59	2.48
	Logistic Power	25.33	31.10	-5.01		1984.43	2.46
	Weibull	36.83	36.97	0.00	3.63	2012.44	2.5
	MMF	-3.67	285.93	55.48	1.27	2324.63	2.89
	Ratkowsky	21.01	6.67	0.22		1977.58	2.47
	Logistic	21.01	785.33	0.23		1977.58	2.45

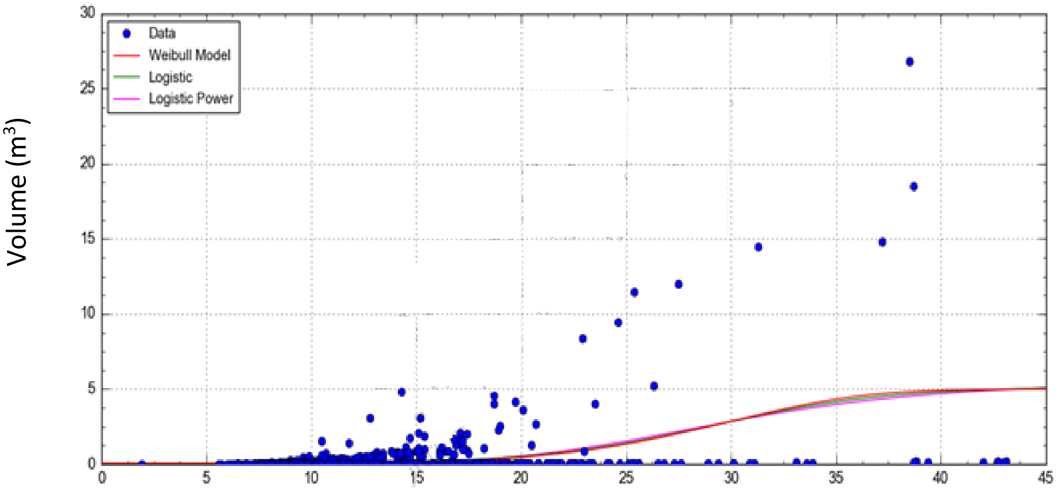

Figure 1: Graph Showing the Results for the best Non-Linear Volume Models Developed for Okpon Forest Reserve, Cross River State, Nigeria

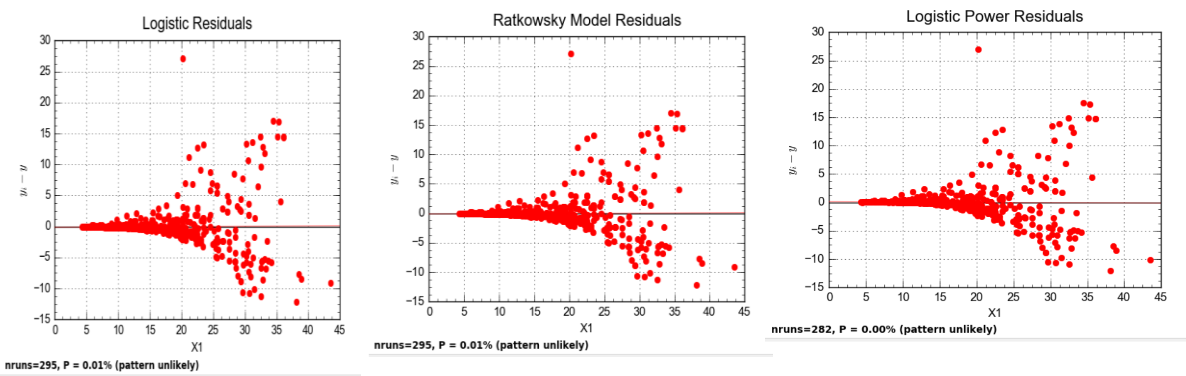

Figure 2: Residual plots for Best three Selected Volume Models for Okpon Forest Reserve

DISCUSSION

Stand-level linear regression volume model was developed for Okpon Forest Reserve in Cross River State. The model generated between stand volume and stand basal area using the simple linear model, logarithm transformed, binomial and polynomial models were assessed and validated with several statistical criteria that were recommended by Vanclay (1988). Similar model form was found suitable by Maguire and Hann (1990) and Adesoye and Osho (2006). The polynomial model ($V = 222.913-1.439X -33.387X^2 -34.695X^3 + 1.654E\text{-}005X^4$) performed statistically better using the assessment criteria (higher R^2, higher Adjusted R^2, and high F-ratio and low standard Error of Estimate) and therefore considered to be a best fit model for volume determination in the Forest Reserve. Polynomial model is one of the linear volume models established to be suitable for volume estimation of rainforest ecosystem (Adekunle *et al.*, 2004). To further test the validity, accuracy and consistency of the selected model, validation tests carried out revealed very lower bias percentage and there were no significant differences between the observed and the predicted values, which further imply that the model is fit for tree volume estimation in the Okpon Forest Reserve (Adekunle *et al.*, 2004).

The study also tested the efficacy of nonlinear models for individual tree volume estimation in the Okpon tropical rainforest of Cross River State. Logistic Power, Logistic, Ratkowsky, MMF, Gompertz Relation, and Weibull models were considered suitable for describing the volume-diameter relationship in the study areas. This is in agreement with the findings made by Adesuyi *et al.*, (2020) that Logistic Power, Logistic, Gompertz Relation, Ratkowsky, MMF, and Weibull model were considered suitable for describing the volume-diameter relationship in strict nature reserve, South-West, Nigeria; but however, Gompertz Relation was the most flexible for volume estimation based on the assessment criteria (AIC and standard error). Basically, the high values found for the coefficients of determination and adjusted R^2 and the small values for standard errors of estimate (SEE) show that the model form is well adapted and biologically realistic. This agrees with Adekunle, (2007) who stated that for a model to be accepted, the coefficient of determination must be high ($> 50\%$) and mean square error must be relatively small. This further confirms the claim made by Thomas, (1977).

CONCLUSION

Remarkable development of models remains a valuable tool on policy, monitoring and supply systems as interventions in combating the challenges of sustainable forest management in the study area. The effectiveness of sustainably managing the reserve depends greatly on the formulation of accurate, easy-to-understand and up-to-date and location specific models. This research study therefore generated and tested the efficacy of linear and nonlinear models for tree volume estimation in Okpon rainforest reserves in Cross River State.

RECOMMENDATIONS

i. Permanent sample plots should be established in the study areas to enhance and promote accurate data collection, and the development of models for informed management decisions.

ii. Further and comprehensive studies involving parameter prediction and parameter recovery methods taking information provided in this study as a foundational resource should be carried out across the study areas.

iii. All the models developed in this study were discovered to be very adequate for yield estimation and are recommended for tree volume estimation in the tropical natural forest ecosystem of Cross River State and in any similar ones.

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