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UNICROSS JOURNAL OF SCIENCE AND TECHNOLOGY, UJOST

RESEARCH ARTICLE VOL. 3(4) DECEMBER, 2024 ISSN:2814-2233

Date Approved December 31, 2024 Pages 100 –117

NON-LINEAR MODELS FOR INDIVIDUAL TREE VOLUME AND ABOVEGROUND BIOMASS ESTIMATION IN BOSHE FOREST RESERVE, CROSS RIVER STATE, NIGERIA

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Abstract

The aim of this research study is to develop non-linear models for the estimation of tree volume and aboveground biomass for Boshe tropical rainforest reserve of Cross River State, Nigeria. Systematic line transects sampling method which involved the establishment of two parallel lines transects of 1500m in length with a distance of 500m between them was used for this study. Ten sample plots of 50m X 50m in size were laid in alternate along each transect at 100m interval. So, a total of 20 sample plots were enumerated. All tree species encountered in each sample plots were identified with their botanical names. In addition, tree growth variables such as dbh, height and diameters at the base, middle and top of every living tree in each plot with dbh >10cm were identified and measured for this study. Non-destructive method of biomass estimation was adopted. Diameter at breast height and total height were used to determine the aboveground green biomass for each tree. Conversion factors were applied to estimate stand biomass, carbon sink and sequestered carbon dioxide (CO_2) for the forest reserve. Non-linear models were developed for volume and aboveground biomass estimation in the study area. All the models were assessed and validated using some statistical criteria. Models with good fit were recommended for use. Curve Expert Software was used for the development of the non-linear regression models. The Boshi Forest Reserve had a total value of 374N ha^{-1} for number of stem per hectare, 15 tree families, mean dbh of 25.57cm, height of 16.2m and basal area of $49.35m^2h^1$. The volume, aboveground green biomass, dry biomass, carbon stock and carbon dioxide absorption of $261.708m^3$ ha^{-1}, 452.9711 t ha^{-1}, 328.4041 t ha^{-1}, 164.2020 t ha^{-1} and 602.6214 t ha^{-1} respectively were obtained. The Weibull, Ratkowsky and Logistic models were the best non-linear volume models for the forest reserve. There was no significant difference in the observed and predicted values of both for family-specific and stand level linear regression models (Paired T-test at $p < 0.05$).

Key Words: Non-linear, Aboveground biomass, Dry biomass, Models, Rainforest and Reserve

1.0 Introduction

FAO (2005) has defined biomass as the organic material both above and below the ground, and both living and dead, e.g., trees, grasses, tree liters, roots etc. Aboveground biomass, belowground biomass, dead wood, liter, and soil organic matter are the main carbon pools in any forest ecosystem (FAO, 2005; IPCC, 2003; IPCC, 2006). Above-ground biomass (AGB) includes all living biomass above the soil, while below-ground biomass (BGB) includes all biomass of live roots excluding fine roots (<2mm diameter). Forest biomass is measured either in terms of fresh weight or dry weight. For the purpose of carbon estimation, dry weight is preferred as dry biomass roughly contains 50% carbon (Brown, 1997; IPCC, 2003). Majority of biomass assessment are done for aboveground of trees because these generally account for the greatest fraction of total living biomass in a forest and do not pose too many logistical problems in the field measurement (Brown, 1997).

There is considerable interest today in estimating the biomass of forests for both practical forestry issues and scientific purposes (Parresol, 1999; Ten *et al.,* 2007). However, the quantification of biomass or carbon pools of a forest suffers from a number of methodological problems. Accurate biomass estimation requires locally applicable tree biomass equations. Unfortunately, not all forests do have such equations. Some tree variables, including volume and biomass are extremely time-consuming to measure in field inventories, and need to be predicted by using statistical prediction models prepared in surveys separate to those of operational forest inventories. However, in many cases, there are no models available for predicting different volume and biomass components that are location specific and based on data covering the entire target area of forest inventory. Due to the increasing importance of the carbon-sequestration and REDD+ related assessments, new demands are also set for the country-level forest inventories including up-to-date, accurate easy-to-use and multifunctional models for predicting biomass attributes for trees and forests comprising not only the above-ground but also the below-ground components of biomass.

Furthermore, according to Turner (2001), the tropical rainforest 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 for wood and wood products. FAO (1999) estimated that tropical countries are losing 127,300 km^2 of their forest annually. In view of the great value of the tropical rainforest 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. Estimating tree volume is important for forest management purposes such as assessment of growing stock, timber valuation, selection of forest areas for harvests, and for growth and yield studies (FAO, 1999).

Though, large numbers of stem volume and tree biomass equations exist in literatures; but it is really more difficult to decide which model form is most appropriate for a particular forest type and very often, it is unknown how many trees of what species were used and how they were selected for the development of models. The unclear description of the existing equations regarding the range of DBH, cover type, geographical location and the management systems for which they are applicable makes their use and estimate uncertain. It is within these backgrounds that this research explored the feasibility of developing non-linear models for the estimation of tree volume and aboveground biomass in Boshe Forest Reserve of Cross River State.

2.0 METHODOLOGY

2.1 Study Area

The Boshe Forest Reserve is located on Latitude 6°17′00″N and Longitude 9°14′00″E at an elevation of between 150 and 1,700 m above sea level. The forest has an area of about 92,000 ha. The ground is rugged, with rocky ridges and outcrops. Annual rainfall may be as much as 4,280 mm, mostly falling between March and November. The climate is seasonal-tropical with a distinct rainy season from March to November and dry season from December to February. Rainfall is heavy up to 4,280min distributed unevenly within the nine months. Ambient temperatures are high 18° - 32° C at lower altitudes with daily maxima, temperatures are lower with 14° -16° C (Obot 1996).

2.2 Sampling Procedure and Data Collection

Systematic line transect was employed in the laying of sample plots. Two transects of 1500m in length with a distance of at least 500m between the two parallel transects were used in the 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 forest reserves. In each plot, all living trees with dbh ≥10cm were identified and measured. Spiegel relascope was used for individual tree DBH and other 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 1.30m above ground surface were encountered, the equivalent of dbh was measured at a height of 20cm 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 as recommended by Adekunle *et al.,* (2010).

2.3 Tree Species Identification

All the tree species were identified with their botanical names and distributed into their respective families. The botanical name of every living tree encountered in each sample plot was recorded for each of the sample plot. However, when a tree's botanical name was not known, immediately, it was identified by its commercial name or local name. Such commercial or local name was translated to correct botanical names using Keay, 1989.

3.0 Data Analysis

3.1 Basal Area Estimation

The diameter at breast height was used to calculate the basal area.

$$BasalArea(BA) = \frac{\pi D^2}{4} \quad \text{eq 1}$$

where,

D = diameter at breast height (m)

$\pi =$ 3.142

BA = Basal Area (m^2).

D = diameter at breast height (m)

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:

$$\overline{BA_p} = \frac{\Sigma BA}{n} \quad \text{eq 2}$$

where,

$\overline{\mathrm{BA_p}}$ = Mean basal area per plot and

n = Total number all possible sample plot

3.2 Stem Volume Estimation

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

$$V = \frac{H}{6}[A_b + 4A_m + A_t] \quad \text{.eq 3}$$

where,

V= Volume (m^3)

A_b = Basal area at the base (m^2)

A_m = Mid basal area (m^2)

A_t = Basal area at the top (m^2)

H = height (m)

The plot volumes were 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. Mean volume for the sample plot was calculated thus:

$$\overline{V_p} = \frac{\Sigma V_p}{8} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{eq 4}$$

where,

$\overline{V_p}$ = Mean plots volume

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).

3.3 Biomass and Carbon Stock Estimation

To estimate the Above-ground live biomass, the equation of Brown (1997) for mixed species in the tropical wet climate zone was adopted. The equation is given as:

$$Y = 21.297 - 6.952(D) + 0.740(D^2) \quad . \quad . \quad . \quad . \quad . \quad \text{eq 5}$$

Where:

Y = biomass per tree in kg and

D = diameter at breast height (dbh) in cm.

Below ground biomass was estimated as 15% of the above ground biomass (MacDicken, 1997).

3.4 Aboveground Green Biomass Estimation

The summation of the biomass that was calculated for all trees in a sample produced the total plot biomass (AGB_{plot}). This per plot estimate of aboveground biomass (in kg) was divided by 1000 to express it in metric tons. This was then converted to per hectare estimate (AGB_{ha}) by using the equation:

$$AGBper\ ha = \left(\frac{Ah}{Ap}\right) \times AGBplot \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{eq 6}$$

where,

$GBper\ ha$ = aboveground biomass (metric tons per hectare)

Ah = area of one hectare in m^2

Ap = area of the plot (m^2) (Brown, 1997).

Therefore, to estimate the total biomass of each site, the estimate of biomass of each species was summed up and multiplied with the total size of the forest.

3.5 Aboveground Dry Biomass Estimation

Aboveground dry biomass estimation was calculated from:

$$W = \frac{AGBh \times 0.725}{1000} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{eq 7}$$

Where:

W = aboveground dry biomass (metric tons)

$AGBh$ = aboveground green biomass (kg ha^{-1}) expressed metric ton

(Chaven and Rasal *et al*., (2010)

3.6 Determination of Carbon Sequestration

$$Sc = Wx\ 0.5 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{eq 8}$$

where,

Sc = sequestered carbon (tha^{-1})

W= aboveground dry biomass ($t\ ha^{-1}$)

MacDicken, 1997; IPCC, 2006 and Bassey and Ajayi, 2020) and expressed in t/ha.

3.7 Estimation of Carbon-dioxide Equivalent from Carbon Stock

The content of carbon in woody biomass of any forest is generally 50% of the tree total volume. Hence, to compute the weight of carbon stock of a tree was obtained by multiplying the dry weight of the tree by 50% (Eneji *et al.*, 2014). Therefore, the equation for the measurement of carbon-dioxide equivalent is given as:

$$\text{Carbon dioxide emission} = Sc\ X\ 3.67 \quad . \quad . \quad . \quad . \quad . \quad \text{eq 10}$$

where,

Sc = sequestered carbon (Ajayi and Adie, 2019).

3.8 Generation of Non - Linear Tree Volume and Aboveground Biomass Models

For the Non-Linear Tree Volume and Aboveground Biomass Models, field inventory data were divided into two. The first set (calibrating set) which comprises of 70% of the data was used to generate the models while the second set which comprises of 30% of the data was used to validate the models. The two models were generated using Curve Expert Professional software. The non-linear regression models generated using the model functions presented in Tables 1 and 2 for tree volume and biomass respectively.

Table 1: Non Linear Tree Volume Models

Model	Model Functions
Logistic Power	V = a/(1+(x/b)**c)
Gompertz Relation	V = a*exp(-exp(b-c*x)
MMF	V = (a*b + c*x^d)/(b + x^d)
Weibull	V = a - b*exp(-c*x^d)
Logistic	V = a/(1 + b*e^(-cx))
Ratkowsky model	V = a / (1+exp(b-c*x))

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

Table 2: Non Linear Aboveground Biomass Models

Model	Model Functions
Logistic Power	Y = a/(1+(x/b)**c)
Gompertz Relation	Y = a*exp(-exp(b-c*x))
MMF	Y = (a*b + c*x^d)/(b + x^d)
Weibull	Y = a - b*exp(-c*x^d)
Logistic	Y = a/(1 + b*e^(-cx))
Ratkowsky model	V = a / (1+exp(b-c*x))

a, b, c and d are the regression parameter to be estimated, Y is the Biomass (t) and x is the Dbh (cm) while exp. is the exponential.

3.9 Criteria for Non-linear Volume and Biomass Model Selection

All the non-linear models were 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:

$$SSE = \sqrt{\frac{\Sigma[y_i - \hat{y}_i]^2}{n-p}}$$ ……………………………………………………………eq 11.

Where:

y_i = Actual tree volume

$\hat{y}_i$= Predicted treevolume

i. 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 Criterion (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 equation as thus:

$$AIC = 2Logp(L) + p \qquad . \quad . \quad . \quad . \quad . \quad . \text{ eq } 12$$

Where,

L refers to the likelihood under the fitted model and

p is the number of parameters in the model.

3.10 Model validation

Residual graphs were used for the validation of the volume and biomass models selected in the study.

4.0 RESULTS

4.1 Summary of Growth Variables of the Study Area

Results is Table 3 shows that a total of 1496

individual trees (dbh ≥5cm) were identified and measured in the sampling plots with number of stem per hectare of 374N ha-1. Reserve further recorded a mean dbh value of 25.57cm, mean total height of 16.2m, basal area of 49.35m2ha-1 with a stand volume of 261.708M3 ha-1 with a stand aboveground green biomass ranged of 452.97t ha-1 and dry biomass value of 328.40t ha-1.

Table 3: Summary of Growth Variables of the Study Area

S/N	Parameters	Mean	Min.	Max.	Std. Error	Std. Deviation	Skewness	Kurtosis
1	No. of sample plots measured	20						
2	No of trees measured	1496						
3	Number of stem per hectare	374N ha^{-1}						
4	DBH(cm)	25.57	4.00	195.10	0.7883	26.03	3.11	14.17
5	Height (m)	16.40	12.21	50.15	0.55	19.14	2.72	8.55
6	Basal area. (m^2 ha^{-1})	49.30	35.01	63.20	0.88	30.21	2.53	15.30
7	Tree volume (m^3)	18.60	8.23	15.19	0.34	15.51	1.75	9.42
8	Tree green biomass (kg)	74.44	61.75	107.12	0.85	33.45	3.54	14.13
9	Stand volume (Ha^{-3})	261.71	90.20	238.12	0.53	73.51	2.41	9.33
10	Stand green biomass (ton ha^{-1})	452.971	310.22	970.19	17.745	79.35	-512	-785
11	Stand dry biomass (ton ha^{-1})	328.404	192.90	412.16	12.865	56.54	-512	-864

4.2 Non-Linear Volume Models and their Assessment Criteria

The non-linear models considered for screening were Logistics, Gompertz Relation and Logistic Power, Ratkowsky, Richards, MMF, and Weibull models. However, all the screened models were found to be good models in describing diameter-volume relationship of trees in the study area. Results in Table 4 shows that Weibull model was best followed by Logistic Power and MMF models based on the assessment criteria of the models (lowest AIC and standard error values). Figure 1 shows three best non-linear tree volume models for the reserve; meanwhile Figure 2 shows 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.

Table 4: Non-Linear Volume Models and their Assessment Criteria for Selected Forest Reserves

Forest Reserves	Models	Parameters Estimate				AICC	Std Error
		A	B	C	D		
	Logistic	5.62	29.82	-5.54		243.52	1.09
Boshi	Power						
	Gompertz	-	-	-	-	-	-
	Relation						
	Weibull	5.00	4.94	0.00	5.61	232.79	1.08
	MMF	-1.03	109.04	11.33	1.01	353.20	1.13
	Ratkowsky	-	-	-	-	-	-

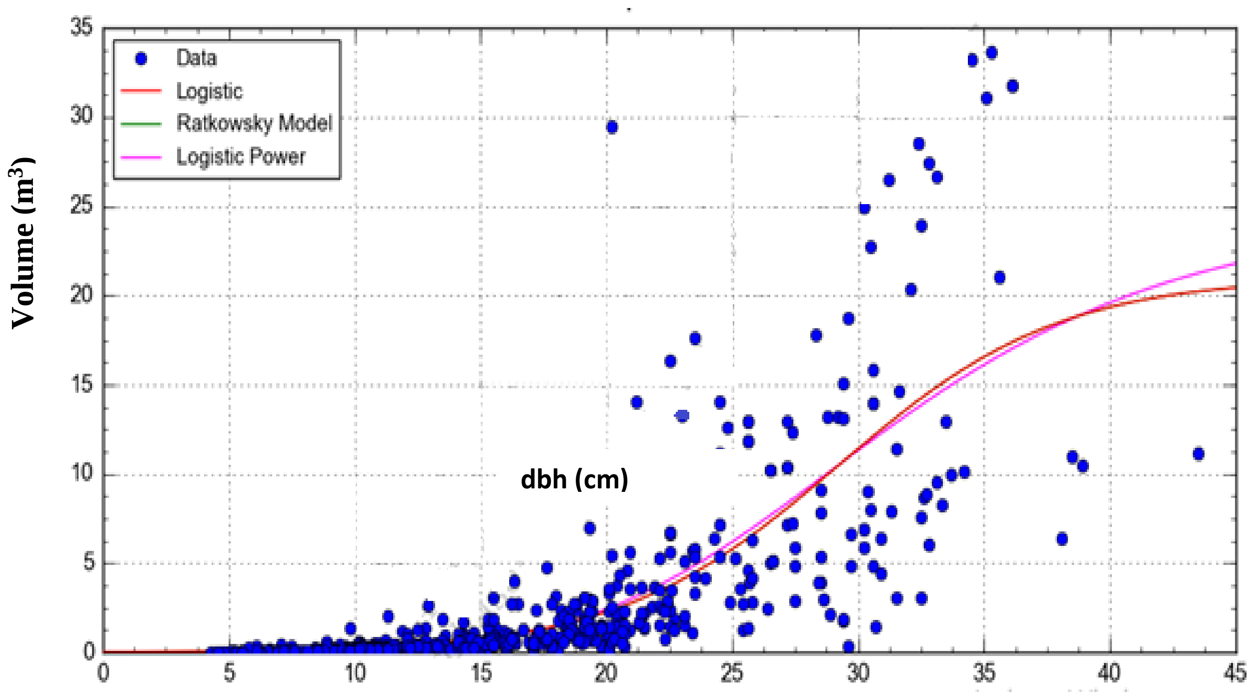
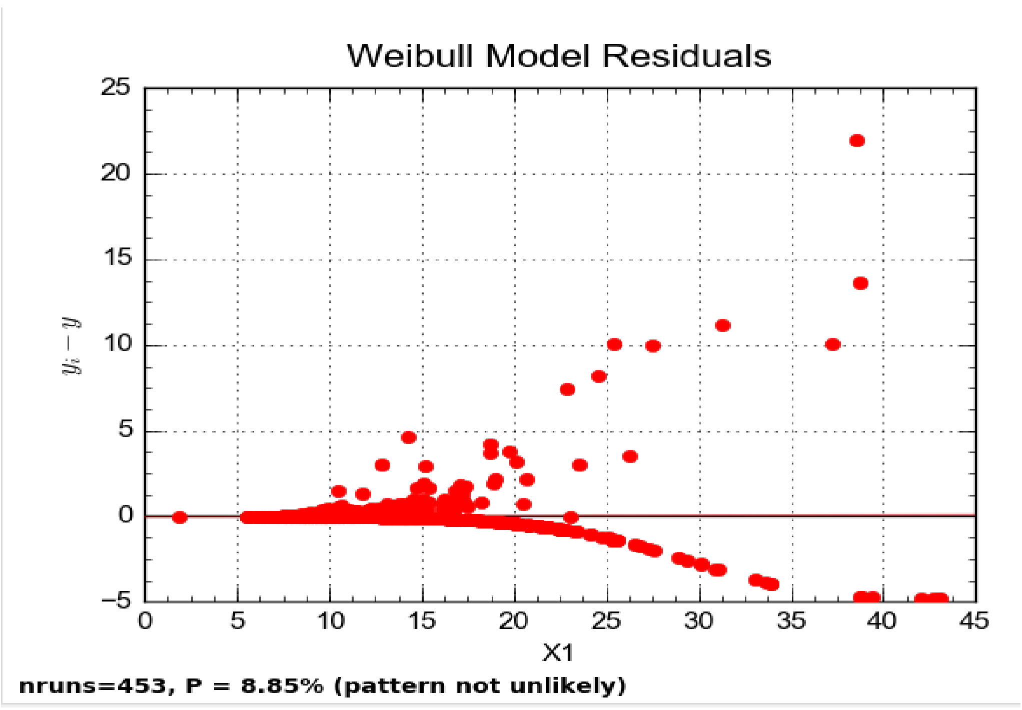
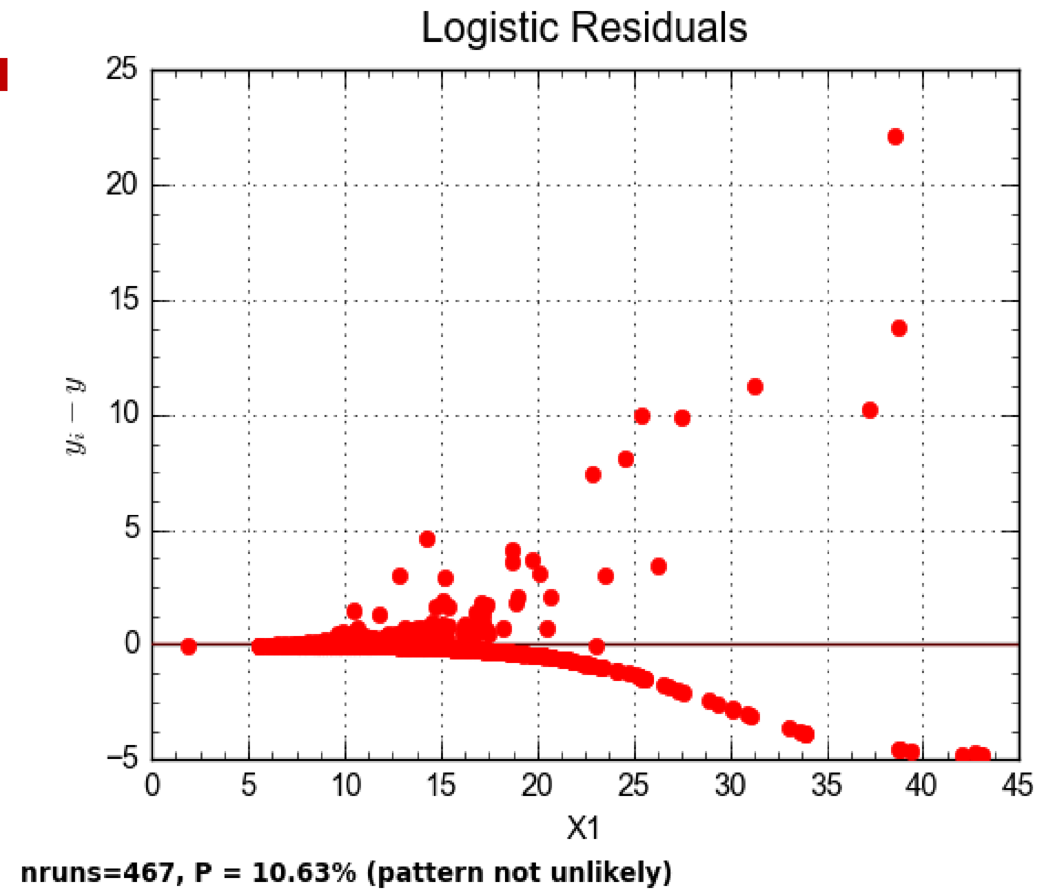


Figure 1: Graph Showing the Results for the best Non-Linear Volume Models Developed for Boshe Forest Reserve, Cross River State, Nigeria.





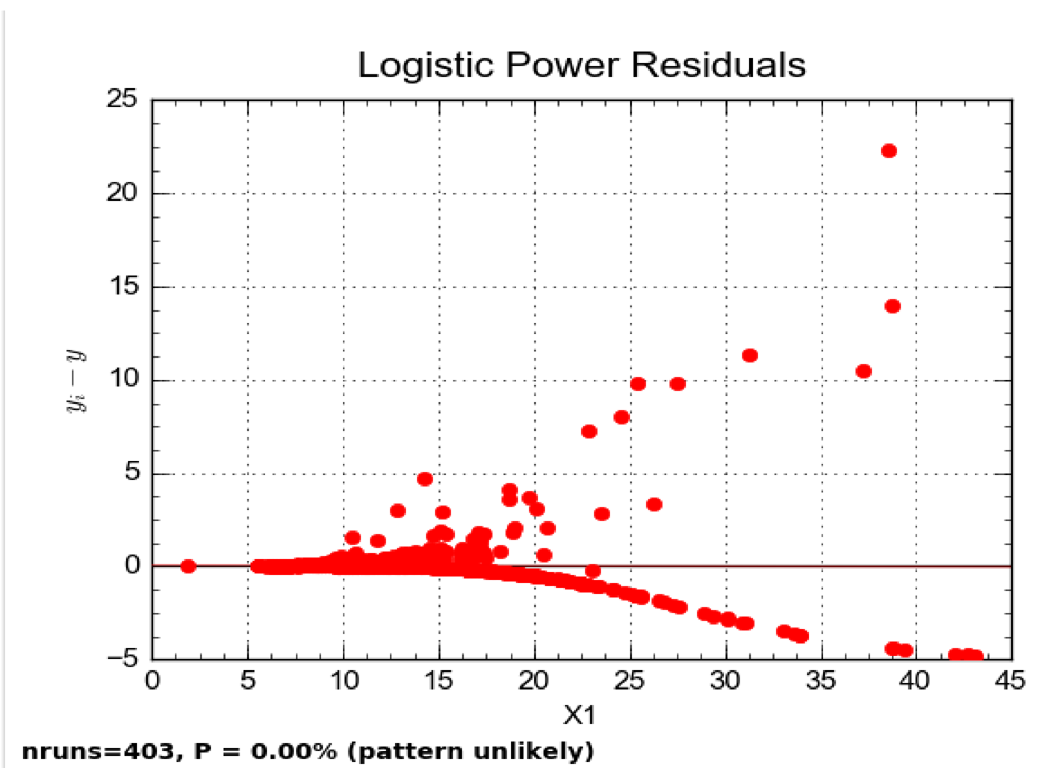


Figure 2: Residual Plots for Best Three Selected Volume Models

4.3 Non-Linear Aboveground Tree Biomass Models and their Assessment Criteria

The non-linear aboveground tree biomass models considered for screening were Logistics, Gompertz Relation and Logistic Power, Ratkowsky, Richards, MMF, and Weibull models. The results in Table 5 shows the best models for non-linear models generated for the aboveground biomass estimation in the Boshi rainforest reserve of Cross River State. Recommendation was based on the model assessment criteria (lowest AIC and standard error values). Logistic model ranked best followed by Logistic Power, Ratkowsky, MMF, Richards and Gompertz Relation respectively. Figure 3 shows the best non-linear tree aboveground biomass model for the reserve while Figure 4 presents the residual plots for the selected three best nonlinear aboveground biomass 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 biomass estimations.

Table 5: Non-Linear Aboveground Biomass Models and their Assessment Criteria

Forest Reserves	Models	Parameters Estimate				AIC	Std Error
Boshe	Gompertz Relation	19.58	2921.32	326.60		1077.48	1.44
	Logistic Power	39.09	35.98	0.01		892.29	1.35
	Richards	19.58	-8.72	282.38		895.43	1.35
	MMF	24.10	1.48	13.46	0.03	894.30	1.35
	Ratkowsky	19.58	769.93	110.69		893.42	1.35
	Logistic	19.50	-0.02	0.07		891.52	1.35

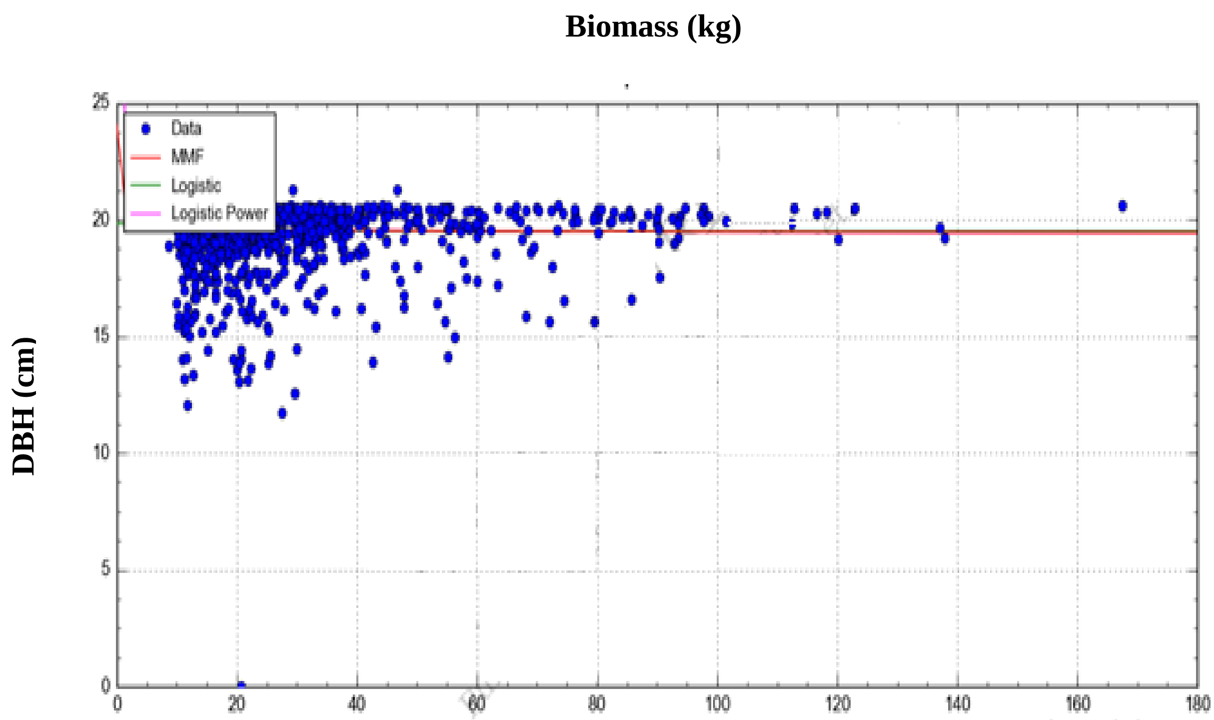
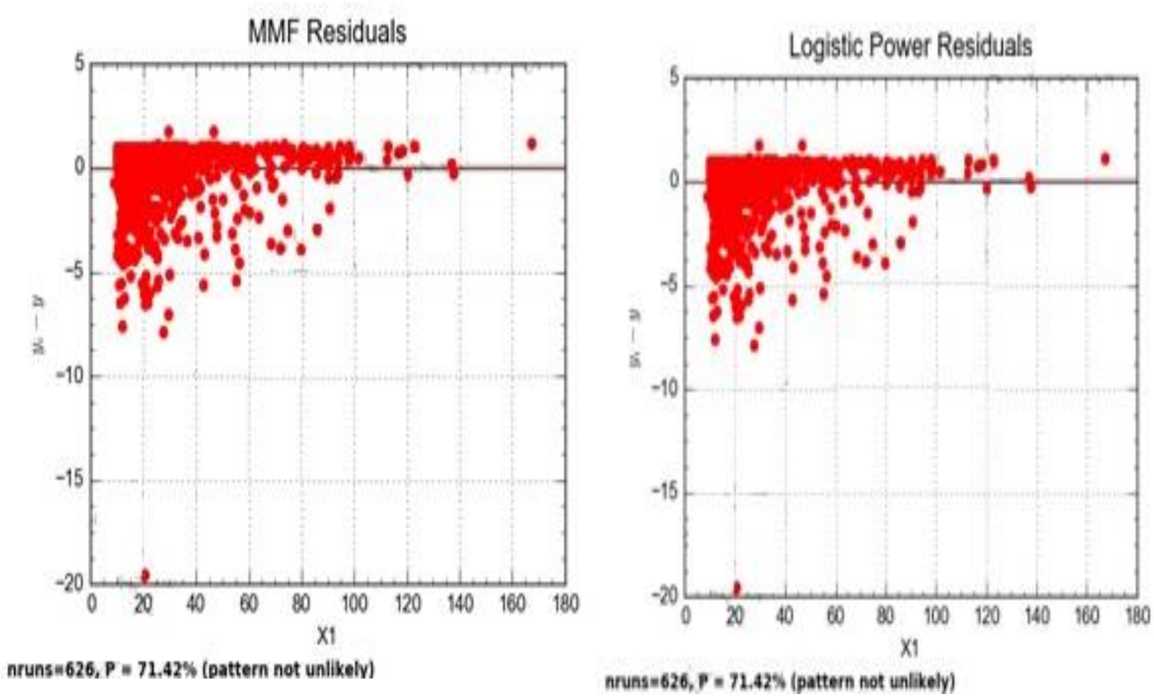


Figure 3: Graph Showing the Results for the best Non-Linear Aboveground Biomass Models Developed for Boshi Forest Reserve, Cross River State, Nigeria.



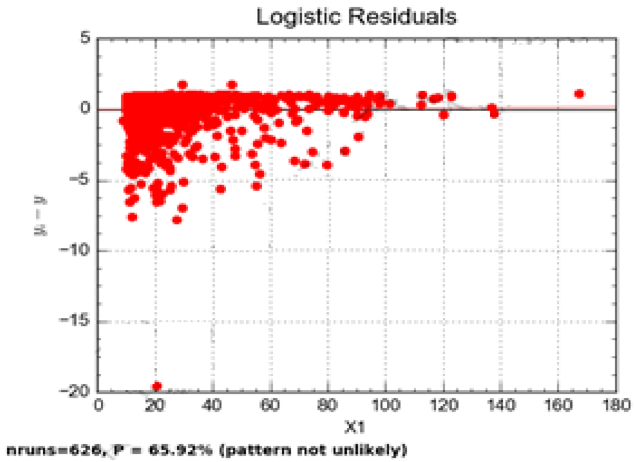


Figure 4: Residual Plots for Best Three Selected Volume Models

5.0 Discussion

This research tested the adequacy of nonlinear models for tree volume and aboveground biomass estimation in the Boshi Forest Reserve of Cross River State. Logistic Power, Logistic, Ratkowsky, MMF, Gompertz Relation, and Weibull models were considered suitable for describing the volume and tree diameter relationship and also biomass and tree diameter in the study area. This is in agreement with the findings made by Adesuyi *et al.*, (2020) that Logistic Power, Logistic, Gompertz Relation, Ratkowsky, MMF, and Weibull models were suitable for describing the volume-diameter relationship in strict nature reserve, South-West, Nigeria. However, Logistic model was the most flexible for volume estimation based on the assessment criteria (least AIC and standard error). This result further revalidated the claims earlier made by previous authors (Nelson *et al.*, 2020). Therefore, the non-linear models generated and validated for both volume and biomass can fitly be used to estimate tree volume and aboveground biomass in the study area.

6.0 Conclusion and Recommendations

The effectiveness of sustainably managing a reserve depends greatly on the formulation of accurate, and up-to-date and location specific models. This research therefore generated and tested the efficacy of nonlinear models for tree volume and aboveground estimation in Boshi Forest Reserve of Cross River State. Logistic model was the most appropriate for the estimation of tree volume and Weibull model was best for aboveground tree biomass in the Forest Reserve.

1. Permanent sample plots should be established by the Cross River Forestry Commission in the study area to enhance and

promote accurate data collection, and the development of models for informed management decisions.

2. Models developed in this study are very adequate for yield estimation and are therefore recommended for tree volume and aboveground biomass estimation in the study area and in any similar ones.

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