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NON-LINEAR MODELS FOR TREE VOLUME AND ABOVE GROUND BIOMASS ESTIMATION IN AFI RIVER FOREST RESERVE, CROSS RIVER STATE, NIGERIA

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ABSTRACT

The research aimed at developing non-linear models for tree volume and aboveground biomass estimation in Afi River Forest of Cross River State, Nigeria. Two transects of 1500m in length with a distance of 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 1368 individual tree species spread across 23 species belonging to 18 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 (dbh) and total height of 25.8cm and 18.5m were respectively obtained while12.01 m^3 and 80.72 kg were obtained for average tree volume and biomass respectively. At stand level, mean basal area of 48.95$m^2 ha^{-1}$ was obtained with a mean volume of 244.561m^3 $ha^{-1}$and mean green biomass was 448.860ton $ha^{-1}$with a dry biomass of 325.423ton ha^{-1}. Curve Expert software was used for model's development. For tree volume estimation, Weibull model was the most flexible, however, Logistic models and Gompertz Relation models were most flexible for aboveground biomass estimation based on the assessment criteria (AIC and standard error) and therefore recommended as the best fit models for individual tree volume and aboveground biomass estimation in the study area.

Keywords: Models, Systematic sampling, Transect, Non-linear and Biomass

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INTRODUCTION

Deforestation, forest degradation and land use change are the main sources of carbon emissions from developing countries, accounting for 15–20% of global carbon emissions (Angelsen, 2008). The increase in the concentrations of carbon-dioxide (CO2) and other greenhouse gases (GHG) in the atmosphere are the main drivers of the changes in the earth's environmental conditions and global climate (IPCC, 1990). Green House Gases (GHG) emission has been one of the most urgent issues of concern worldwide as the main anthropogenic cause of climate change. Atmospheric concentration of CO_2 now exceeds pre-industrial levels by 40% and increasing CO_2 concentration is the single biggest driver of global climate change (IPCC, 2013). Land use change is the second biggest contributor to global anthropogenic CO_2 emissions (IPCC, 2013). An estimated 15% (range 8-20%) of annual global anthropogenic CO2 emissions results from forest degradation and conversion of forest land to other uses occurring primarily in the tropics (FAO and JRC, 2012).

Concern regarding the impact of CO_2 emissions arising from deforestation and degradation on the global climate has led to increased emphasis on estimating current carbon stocks within the world's forests and changes to these stocks. Robust estimates of forest carbon stocks and stock changes are crucial in order to constrain uncertainties in regional and global carbon budgets and predictions of climate change made using earth systems models (Valentini *et al.,* 2014). Such estimates are also a key requirement for international forest-based climate change mitigation strategies such as Reducing Emissions from Deforestation and Forest Degradation (REDD$^+$).

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. The development of effective and accurate models to predict forest volume and biomass is essential for forest managers and planners. 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). Furthermore, due to the increasing importance of carbon-sequestration and Reducing Emissions from Deforestation and Degradation related assessments, new demands are also set for the country-level forest inventories including up-to-date, accurate and multifunctional models for predicting biomass attributes comprising not only the above-ground but also the below-ground components of biomass and also for yield growth.

MATERIALS AND METHODS

Study Area

Afi River Forest Reserve lies approximately between Latitudes 6º 08´ and 6º 26´N and Longitudes 8º 50´ and 9º 05´E and covers a total land area of 383.32 km^2 including the area known as Afi Mountain. The topography of the study area is extremely complex with many connected ridge systems, isolated peaks and outcrops, with altitude ranging from 200 to 1200m above sea level. The reserve is characterized by large tracts of rock outcrops especially on the North-East axis. The hills of the reserve are extension of the Cameroon Mountains geological formation. The fast moving and high gradient streams drain the Afi River Forest Reserve, constituting an important watershed.

Crustaceous sedimentary sandstone occupies a significant area of the study site, with volcanic eruptions that sometimes comprises columnar basalt in some places (Nsor, 2004). Old sedimentary soils tend to be sandy with structure less profiles and incipient laterite. Generally, the soils vary from clayey-loam to loamy-clay and normally red with high content of iron oxide. They are acidic and low in nutrient status, which makes them unsuitable for arable crop production (Agbor, 2003) Annual rainfall varies from 3,000 mm to 3,800 mm (Agbor, 2003) while the mean annual temperatures are 22.2ºC and 27.4o C on Afi mountain and lowland, respectively. Balogun, (2003) indicated that the mean annual relative humidity is 78% at 7.00 Hr. The vegetation of Afi River Forest Reserve generally falls within the tropical high forest vegetation zone. The rainforest occupies the foot of the mountain. At about 700m above sea level, the forest structure changes gradually into sub-montane vegetation, while above 500m, the vegetation has been changed into grassland as a result of annual bush fire (Agbor, 2003).

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 site. 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 1.30 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 as recommended by Adekunle *et al.*, (2010).

Data Analysis

Basal Area Estimation

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

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

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

The mean 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:

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

where; $\overline{BA_p}$ = Mean basal area per plot

Stem Volume Estimation

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

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

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 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. 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, 2010).

Biomass and Carbon Stock Estimation

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

$$Y = 21.297 - 6.952(D) + 0.740(D^2) \ldots \ldots \ldots 4$$

Where; Y = biomass per tree in kg and D = diameter at breast height (dbh) in cm.

Aboveground Live Green Biomass Estimation per Hectare

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

$$AGBper\ ha = \left(\frac{Ah}{Ap}\right) \times AGBplot \ldots \ldots \ldots \ldots 5$$

Where: AGBha = aboveground biomass (metric tons per hectare)

Ah = area of one hectare in m^2, Ap= area of the plot (m^2) (Brown, 1997).

Aboveground Dry Biomass Estimation

Aboveground dry biomass estimation was calculated from:

$$W = \frac{AGBh\ \times 0.725}{1000} \ldots \ldots \ldots 6$$

Where: W = aboveground dry biomass (metric tons)

AGB_h = aboveground green biomass (kg ha^{-1}) expressed metric ton (Chaven and Rasal *et al*., (2012)

Construction of the Non-linear Regression Models for Tree Volume and Biomass Estimation

Volume and biomass equations are mathematical expressions which relate tree volume and biomass to tree's measurable attributes such as diameter at breast and/or height. They are used to estimate volume and biomass contents for standing trees of various sizes and species. The non- linear regression models for volume and biomass in tables 1 and 2 respectively were generated using Curve Expert Professional software.

Table 1: **Non-linear Regression Models for Tree Volume**

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 parameters to be estimated, V is Tree Volume in (m^3), x is the Dbh (cm) while exp. is the exponential.

Table 2: **Non-linear Regression Models for Tree Biomass**

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	Y = a / (1+exp(b-c*x))

a, b, c and d are parameters to be estimated, Y is Tree biomass in (Kg), x is the Dbh (cm) while exp. is the exponential.

Criteria for Volume and Biomass Models Selection

Models were assessed with the Standard error of estimate (SEE) and Akaike Information Criterion (AIC) as follows:

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:

$$SSE = \sqrt{\frac{\Sigma[y_i - \bar{y_i}]^2}{n-p}} \ldots\ldots 8$$

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:

$AIC = 2Logp\ (L) + p..9$

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

RESULTS

Summary of Characteristics data for Afi River Forest Reserve

Results in table 3 below show that a total of 1368 individual trees spread across 65 species belonging to 18 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 (dbh) and total height of 25.82 cm and 18.5m respectively were obtained while10.36 m^3 and 76.31 kg were obtained for average tree volume and biomass respectively. Mean basal area of 50.29 $m^2\ ha^{-1}$ was estimated with a mean volume of 271.249 $m^3\ ha^{-1}$ and mean green biomass was 460.867ton $ha^{-1}$with a mean dry biomass of 334.128ton ha^{-1}.

Table 3: Summary of Characteristics data for Afi River Forest Reserve

S/N	Parameters	Mean	Min.	Max.	Std. Error	Std.	Skewness	Kurtosis
1	No. of sample plots measured	20						
2	No of trees measured	1368						
3	DBH (cm)	38.47	3.00	193.80	0.7883	26.03	3.11	12.27
4	Height (m)	18.6	11.40	46.20	0.55	19.14	2.72	6.84
5	Basal area. ($m^2\ ha^{-1}$)	48.95	36.68	58.46	1.22	5.500	1.386	2.123
6	Tree volume (m^3)	12.01	7.65	14.89	0.34	15.51	1.75	8.34
7	Tree green biomass (kg)	80.72	55.75	102.12	0.85	33.45	3.54	11.83
8	Stand volume (Ha^{-3})	244.561	87.23	234.10	0.53	31.29	-0.257	-1.108
9	Stand green biomass (ton ha^{-1})	488.860	305.77	965.49	17.745	79.35	-512	-992
10	Stand dry biomass (ton ha^{-1})	325.423	188.29	409.98	12.865	56.54	-512	-992

Non-Linear Tree Volume Models and their Assessment Criteria

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 the study area. The results in Table 4 show the best models for non-linear models generated for the stand level volume estimation in the Afi River Forest Reserve of Cross River State. Weibull model recorded best followed by Ratkowsky and Logistic power models. This was later followed by Gompertz Relation, MMF and Logistic models respectively. However, recommendation was done based on the model with the lowest AIC and standard error values. Furthermore, Figure 1 shows the best non-linear tree volume models for the reserve. Furthermore, Figure 1 shows three best non-linear tree volume models for the reserve; meanwhile Figures 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

Table 4: Non-Linear Tree Volume Models and their Assessment Criteria

Forest Reserves	Models	Parameters Estimate				AIC	Std Error
		A	B	C	D		
Afi River	Logistic power	26.79	33.55	-4.92		1883.19	1.99
	Weibull	22.13	21.85	0.00	5.05	1829.66	1.95
	Gompertz Relation	27.99	2.77	0.09		1905.52	2.00
	Logistic	-7.39	-15.49	0.06		2658.93	2.64
	MMF	-3.41	434.04	64.48	1.33	2388.28	2.39
	Ratkowsky	23.80	6.52	0.20		1836.40	1.96

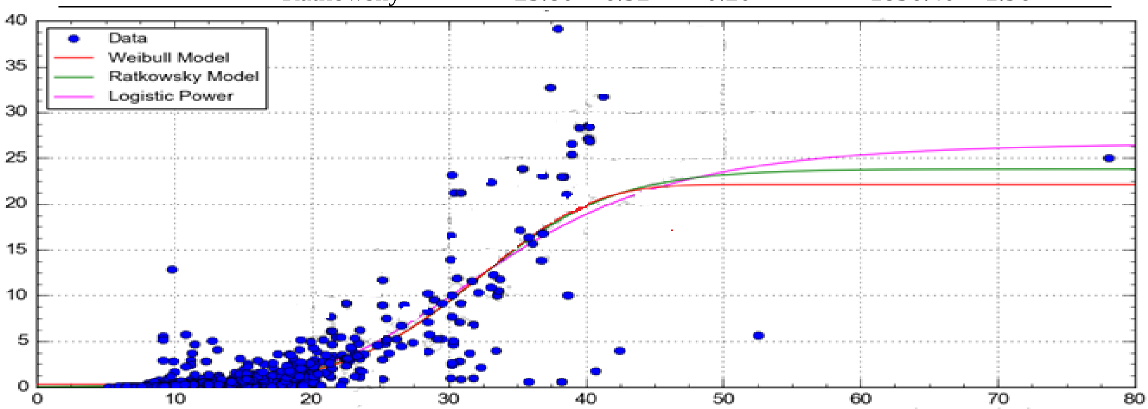

Figure 1: Graph Showing the Results for the Best Non-Linear Stand Volume Models Developed for Afi River Forest Reserve, Cross River State, Nigeria

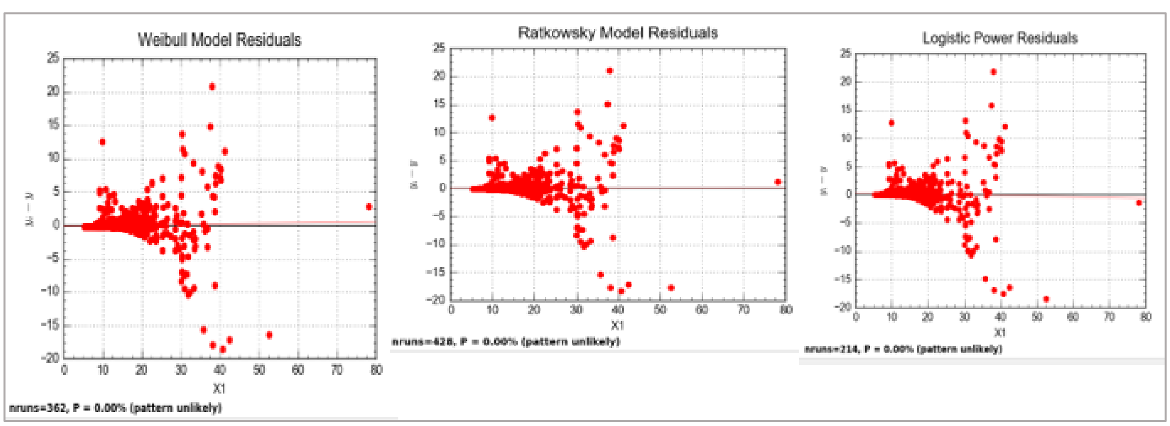

Figure 2: Residual plots for Best three Selected Volume Models

Non-Linear Aboveground tree Biomass Models and their Assessment Criteria

The non-linear aboveground tree biomass 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-biomass relationship of trees in the study area.The results in Table 5 show the best models for non-linear models generated for the stand level aboveground biomass estimation in the Afi River Reserve of Cross River State. Logistic models and Gompertz Relation recorded the same and best, followed closely by Ratkowsky, MMF, and Logistic power and Weibull models respectively. Also, recommendation was done based on the model with the lowest AIC and standard error values. Figure 2 shows the best non-linear volume models for the reserve. Figure 3 shows three best non-linear tree aboveground nonlinear models for the reserve; meanwhile, Figures 4 is the residual plots of 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

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

Forest Reserves	Models	Parameters Estimate				AIC	Std Error
		A	B	C	D		
Afi River	Logistic power	43.71	586.58	-0.01		2401.33	2.40
	Weibull	36.02	59.98	1.38	0.007	2403.34	2.41
	Gompertz Relation	21.51	-3.19	0.10		2400.87	2.41
	Logistic	21.51	0.04	0.10		2400.87	2.41
	MMF	20.62	26.11	21.54	1.63	2402.94	2.41
	Ratkowsky	31.58	-0.73	0.00		2402.07	2.41

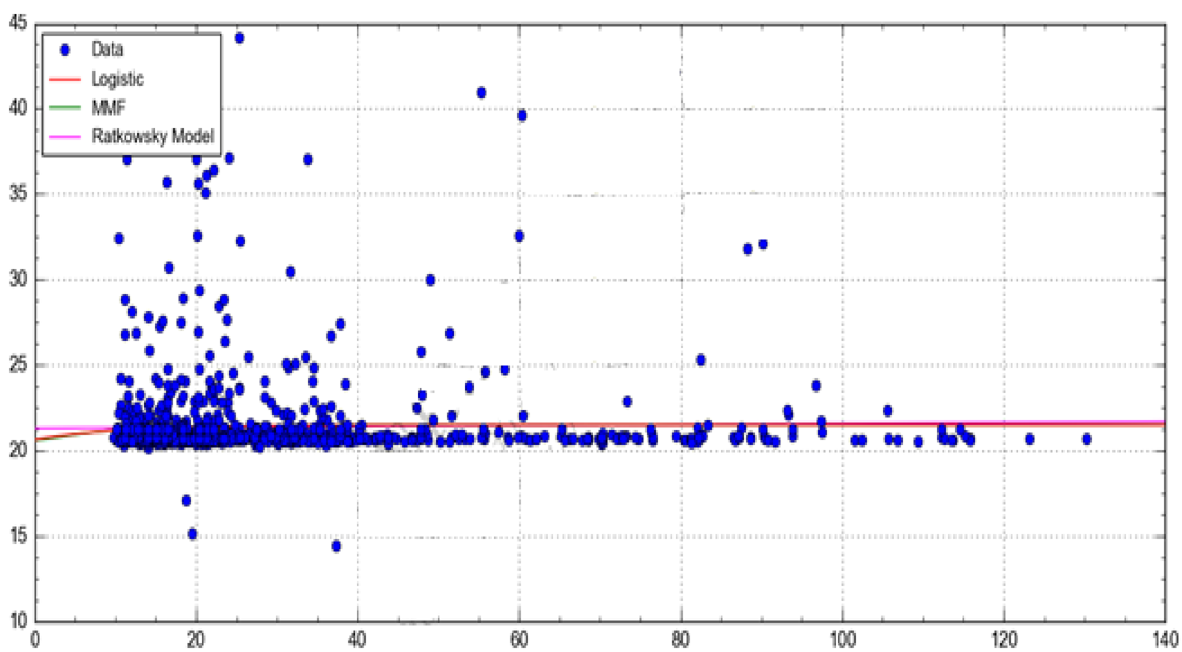

Figure 2: Graph Showing the Results for the Best Non-Linear Stand Aboveground Biomass Models Developed for Afi River Forest Reserve, Cross River State, Nigeria.

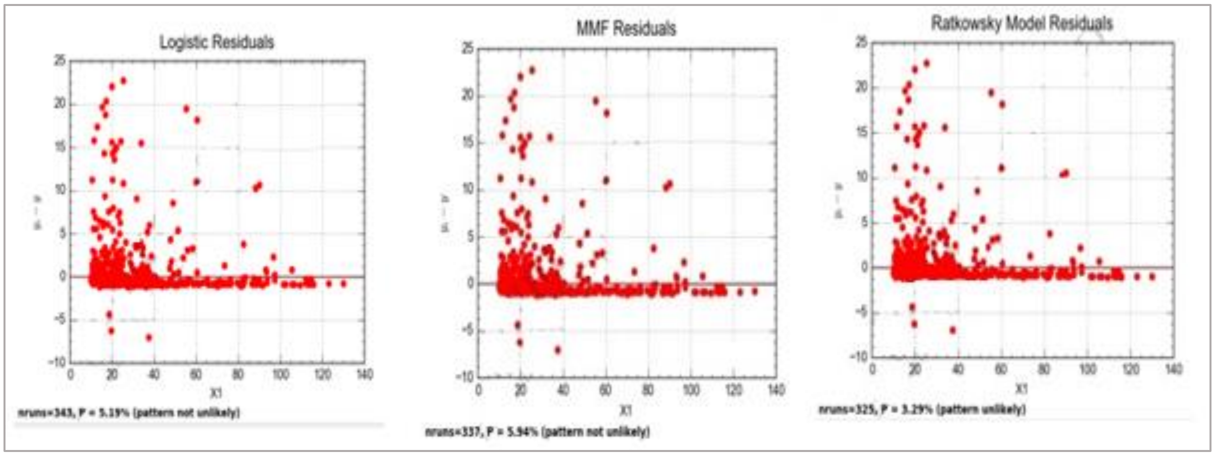

Figure 4 Residual plots for Best three Selected Biomass Model

DISCUSSION

This research study tested the efficacy of nonlinear models for tree volume and aboveground biomass estimation in Afi River Forest Reserve 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 suitable for describing the volume-diameter relationship in strict nature reserve, South-West, Nigeria. However, Weibull was the most flexible for volume estimation based on the assessment criteria (AIC and standard error). Similarly, Logistic Power, Logistic, Ratkowsky, MMF, Gompertz Relation, and Weibull models were considered suitable for describing the aboveground-diameter relationship in the study area. Meanwhile, Logistic and Ratkowsky models were best and more flexible models and therefore recommended as the best fit model for the estimation of the aboveground biomass in the Afi River Forest Reserve. 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.

CONCLUSION

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. 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 from those of operational forest inventories. This research study therefore generated and tested the efficacy of nonlinear models for tree volume and aboveground estimation in Afi River Forest Reserve of Cross River State. Weibull model was the most appropriate model for volume estimation while Logistic Ratkowsky models were the most flexible models for the estimation of the aboveground tree biomass in the Forest Reserve.

Recommendations

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. All the models developed in this study are recommended for tree volume and aboveground biomass estimation in the tropical natural forest ecosystem of Cross River State and in any similar ones.

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