Non-Linear Models for Individual Tree Volume and Aboveground Biomass Estimation in Okpon River Forest Reserve, Cross River State, Nigeria

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Abstract:

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 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 (dbh) and total height of 28.8cm and 18.6m respectively were obtained while10.36 m^3 and 76.31 kg were obtained for average tree volume and biomass respectively. At stand level, mean basal area of 50.29 m^2ha^{-1} was obtained with a mean volume of 271.249 m^3 $ha^{-1}$and mean green biomass was460.867ton $ha^{-1}$with a dry biomass of 334.128ton ha^{-1}. Curve Expert software was used for models development. Logistic model had the least AIC and standard error (SE) values for tree volume and aboveground biomass and therefore recommended as the best fit models for individual tree volume and aboveground biomass estimation in the study area.

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

Introduction

Vanclay (1994) defines models as abstractions of the natural dynamics of a forest stand, which may encompass growth, mortality and other changes in stand composition and structure. 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. Growth and yield models, which rely on functions to measurement data from a sample of the forest population of interests, are the tools that have mainly been used to provide decision support information that meets basic operational needs for evaluating various forest management scenarios (Avery and Burkhart, 2002). 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. Models are used for operational and strategic planning in nations that own and manage forest lands.

The substantial focus has been given to forestry for the development of estimation schemes to predict volume at the individual tree and stand-level due to the ecosystem's economic impact. Periodic inventories are often needed by forest industries and other organization as it helps to determine the quantity of wood utilization. Forest inventory were majorly conducted in plantation or in natural forest with the aim of estimating the timber volume of the plot obtainable in the entire stand. Estimating tree volume is important for forest management due to its effectiveness in the assessment of growing stock, timber valuation, distribution of area allocated for harvest and decision-making process involving the use and management of the forest.

The tropical rainforest is the most diverse of all terrestrial ecosystems, containing more plant and animal species than any other biome. Biomass assessment is important for national development planning as well as for scientific studies of forest ecosystem productivity, carbon budgets, etc. (Pandey *et al.,* 2010). Biomass analysis is an important element in the carbon cycle especially, carbon sequestration. Recently, biomass is increasingly used to help quantify pools and fluxes of greenhouse gases (GHG) from terrestrial biosphere associated with land use and land cover changes (Cairns *et al.,* 2003). The importance of terrestrial vegetation and soil as significant sinks of atmospheric CO_2 and its other derivatives is highlighted under Kyoto Protocol (Wani *et al*. 2010). Vegetation especially, forest ecosystems store carbon in the biomass through photosynthetic process, thereby sequestering carbon dioxide that would otherwise be present in the atmosphere. An estimate indicates that tropical forests account for 247metric tons vegetation carbon, of which 193 billion tons is stored above ground (Saatchi *et al*., 2011).

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 Okpon River Forest Reserve of Cross River State.

Methodology

Study Area

The research was conducted in the Okpon River Forest Reserve located within Obubra, Etung and Yakurr Local Government Areas in Cross River State, Nigeria (Latitudes 5° 40' 30" and 5° 57' 30"N; Longitudes 8° 12' 00"and 8° 32' 00"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 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 27.6⁰ C in August to 33.1⁰ 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 *et al.,* 2006).

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.

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

Where: D = diameter at breast height (m), $\pi = 3.14$ 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:

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

where; $\overline{\mathrm{BA_p}} = \text{Mean basal area per plot} = \text{Total number all possible sample plot plot}$

Stem Volume Estimation

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

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

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 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

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

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

Estimation of the above-ground live biomass was also carried out by multiplying the volume of each tree with its respective wood density. Below ground biomass was estimated as 15% of the above ground biomass (MacDicken, 1997).

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 (in kg) was divided by 1000 to express it in metric tons. This was then converted to per hectare estimate (AGBha) by using the equation:

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

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:

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

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

Determination of Carbon Sequestration

$$Sc = Wx\ 0.5 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

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

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 FUNCTION
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 FUNCTION
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:

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

Where $y_i =$ Actual tree volume

$\overline{y_i}$ = 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:

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

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 Okpon River Forest Reserve

Results in table 3 below show that a total of 1100 individual trees 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 (dbh) and total height of 28.8cm and 18.6m 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}.

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. The results in Table 4 show the best models for non-linear models generated for the stand level volume estimation in the Okpon River Forest Reserve of Cross River State. . Recommendation was done based on the model with the lowest AIC and standard error values. Logistic model was best fit model and very closely followed by Ratkowsky, and Logistic Power, Gompertz Relation, Weibull and MMF models. Furthermore, 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 3: Summary of Characteristics data for Okpon River Forest Reserve

S/N	Parameters	Mean	Min.	Max.	Std. Error	Std. Deviation	Skewness	Kurtosis
1	No. of sample plots measured	20						
2	No of trees measured				1100			
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})	50.29	32.05	60.25	0.88	30.21	2.53	13.4
6	Tree volume (m^3)	10.36	7.65	14.89	0.34	15.51	1.75	8.34
7	Tree green biomass	76.31	55.75	102.12	0.85	33.45	3.54	11.83

	(kg)							
8	Stand volume (Ha^{-3})	271.25	87.23	234.10	0.53	73.51	2.41	7.12
9	Stand green biomass (ton ha^{-1})	867	305.77	965.49	17.745	79.35	-512	-992
10	Stand dry biomass (ton ha^{-1})	334.128	188.29	409.98	12.865	56.54	-512	-992

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

Forest Reserves	Models	Parameter Estimates				AIC	Std Error
		a	B	c	d		
Okpon	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

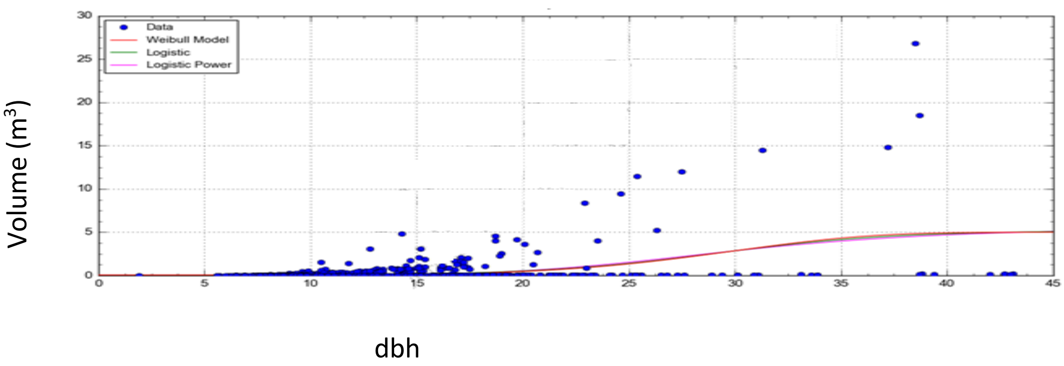
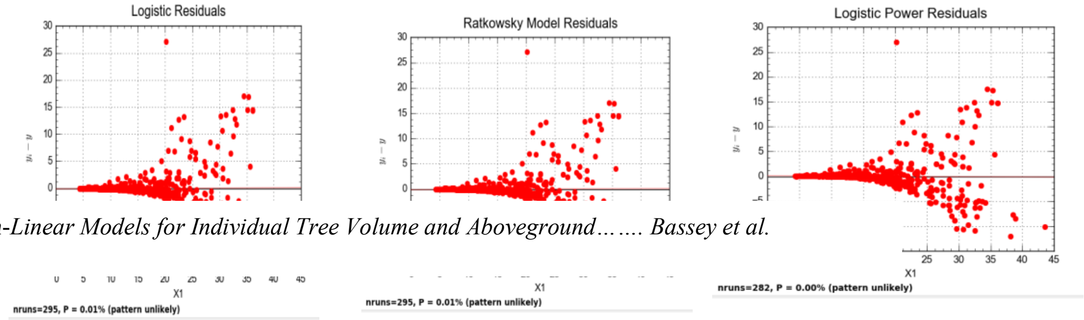


Figure 1: Graph Showing the Results for the best Non-Linear Stand Volume Models

Developed for Okpon Forest Reserve, Cross River State, Nigeria



Non-Linear Models for Individual Tree Volume and Aboveground……. Bassey et al.

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. The results in Table 4 show the best models for non-linear models generated for the stand level aboveground biomass estimation in the Okpon rainforest reserve of Cross River State. Recommendation was done based on the model with the lowest AIC and standard error values. Logistic model was best fit model and followed by MMF, Logistic Power and Gompertz Relation models. Ratkowsky and Weibull models could not fit the biomass –diameter data. Figure 3 shows three best non-linear tree aboveground biomass models for the reserve while Figure 4 Presents 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.

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

Forest Reserves	Models	Parameter Estimates				AIC	Std Error
		a	B	c	d		
Okpon	Gompertz Relation	21.61	2286.08	333.97		2437.98	3.04
	Logistic Power	49.35	14750.40	-0.04		2377.96	2.96
	Weibull						
	MMF	21.04	188.06	26.55	0.95	2374.77	2.95
	Ratkowsky						
	Logistic	413.29	18.52	0.00		2371.24	2.95

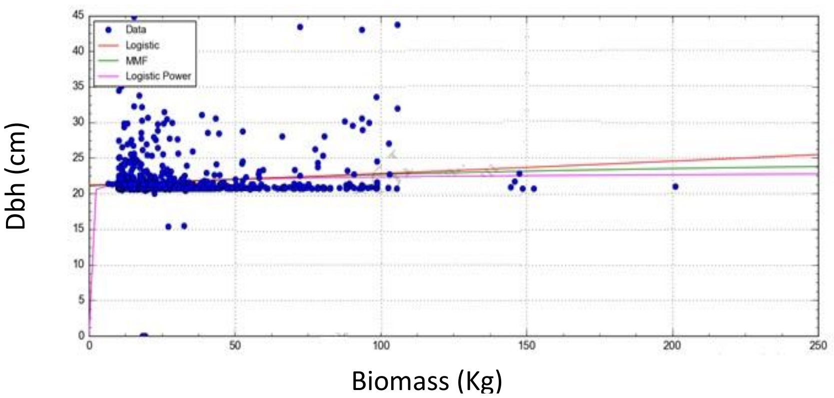
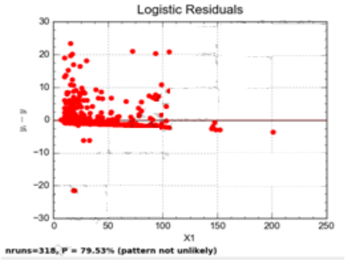
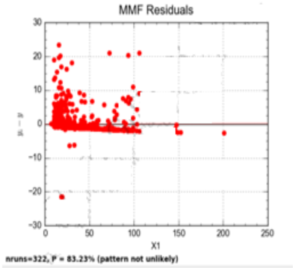
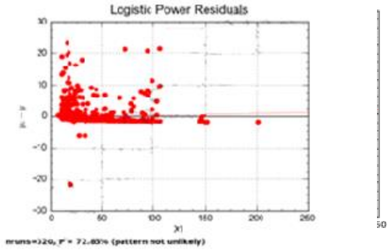


Figure 3: Graph Showing the Results for the Best Non-Linear Tree Aboveground Biomass Models Developed for Okpon River Forest Reserve.



plots





Discussion

The study tested the efficacy of nonlinear models for tree volume and aboveground biomass estimation in the Okpon 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, Logistic model was the most flexible for volume estimation based on the assessment criteria (least AIC and standard error). Similarly Logistic, MMF, Logistic Power Ratkowsky, and Gompertz Relation models were considered suitable for describing the aboveground-diameter relationship in the study area. Logistic model had the least AIC and SE values and therefore recommended as the best fit model for the estimation of the aboveground biomass in the Okpon 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 and Recommendations

Conclusion

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

Recommendations

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. Models developed in this study were discovered to be very adequate for yield estimation and 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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