Diameter Distribution Models and Carbon Sequestration Potential of Afi Forest Reserve, Cross River State, Nigeria

Abstract

Forest managers can make well-informed judgments, including prescribing silvicultural treatments, by being able to forecast the distribution of diameters in a stand. This study calculated the carbon potential of the Afi River Forest in Cross River State, Nigeria, and created and verified models for diameter distribution. For this investigation, two transects totaling 1500 meters in length were used, separated by 500 meters. There were ten sample plots per 1500m transect, or a total of 20 sample plots in the study area, with 50m x 50m sample plots spaced 100m apart throughout each transect. Measurements were made of the diameter at the breast height, the diameters at the base, middle, and top, and the overall height of 1368 individual tree species, distributed among 23 species from 18 distinct tree families. The average tree volume and biomass were found to be 12.01 m3 and 80.72 kg, respectively, while the mean diameter at breast height (dbh) and total height were measured to be 25.8 cm and 18.5 m, respectively. At stand level, mean basal area of 48.95m2ha-1 was attained with a mean volume of 244.561m3 ha-1and mean green biomass was 448.860ton ha-1with a dry biomass of 325.423ton ha-1. Diameter Distribution models were created using the Easy Fit program. Three diameter distribution models were validated for the reserve based on their post-development rankings. Nevertheless, among the chosen diameter models in the reserve, the Log-Logistic (3P) distribution model was determined to have the best fit. Since none of the chosen models was statistically significant, the diameter distribution of the study region can be modeled using all three of the fitted and validated models.

Keywords: Diameter, Distribution Models, Carbon, Systematic sampling, Transect and Reserve

Introduction:

Studying the diameter at breast height is crucial to describing the structure of any particular forest because it is one of the most significant and frequently used bioassay variables in forest trees (Bassey and Adekunle, 2022). In forest research, diameter distribution and related statistical models might be crucial. For instance, in some growth modeling, the type of diameter distribution function and its parameters must be known in order to choose the best model. Diameter distributions can be used to assess future forest sustainability and determine whether the density of smaller trees in a stand is adequate to replace the existing population of larger trees (Bassey and Adekunle, 2022).

In order to promote the productive and protective aspects of the diverse species present, growth models for tropical species have been developed (Gorgoso et al. 2007). Diameter class models have been developed to estimate stand variables and their structure with a density or distribution function that is fitted to diameter distributions at breast height (dbh) or individual tree volume. Forest managers are interested in being able to estimate the number of trees in different diameter classes in a stand because the diameter determines the industrial use of the wood and, consequently, the price of the various products. Diameter distributions also provide information about stand structure, age structure, stand stability, thus, enabling the planning of silvicultural treatments.

Since no single growth model type can be expected to provide information efficiently for all levels of decision making (Adesoye, 2002), a wide variety of models of varying degrees of complexity are required for the management of natural forests and plantations. It is crucial for forest managers to choose systems that emphasize the importance of recreating a specific diameter distribution or stand structure at the end of each cutting cycle (Gottsacker, 2005). This is because models that provide accurate estimates of tree growth and yield have become essential tools for evaluating the numerous management and utilization decisions in the forestry profession.The Dbh of forest trees is a crucial factor in figuring out the forest's volume and, more significantly, its basal area. The forest ecosystem's growth and yield can be predicted or projected using this variable, which is the simplest to measure (Bassey and Ajayi, 2020; Adedeji et al., 2024). Information on the distribution of tree diameters is also essential for making well-informed decisions on product specifications and general forest reserve management.

Assessment of biomass is crucial for scientific research on ecosystem productivity, carbon budgets, and national development planning (Pandey *et al.*, 2010; Bassey and Ajayi, 2020). In the carbon cycle, biomass analysis is crucial, particularly for carbon sequestration. The use of biomass to measure the pools and fluxes of greenhouse gases (GHG) from the terrestrial biosphere linked to changes in land use and land cover has grown recently (Cairns et al., 2003). The Kyoto Protocol emphasizes the significance of soil and terrestrial vegetation as major sinks of atmospheric CO2 and its byproducts (Wani et al. 2010). Through the photosynthetic process, vegetation, and forest ecosystems in particular, sequester carbon dioxide that would otherwise be in the atmosphere by storing it in the biomass. Undisturbed forest ecosystems are often extremely productive and gather more biomass and carbon per unit area compared to other land use systems like agriculture. Tropical forests store 193 billion tons of vegetation carbon above ground, according to a recent estimate of 247 metric tons (Saatchi et al. 2011). Determining diameter distributions and their carbon potentials is, therefore, the primary goal of this investigation.

Methodology

Study Area

The Afi River Forest Reserve spans 383.32 km^2, includes the Afi Mountain, and is roughly located between latitudes 6o 08′ and 6o 26′N and longitudes 8o 50′ and 9o 05′E. With several interconnected ridge systems, solitary summits, and outcrops, the study area's topography is incredibly complicated. Its elevation ranges from 200 to 1200 meters above sea level. In essence, the reserve is defined by large rock outcrops, particularly along the northeast axis. The reserve's hills are a geological extension of the Cameroon Mountains. The Afi River Forest Reserve, a significant watershed, is drained by the swift-moving, steeply sloping streams.

A sizable portion of the research site is composed of crustaceous sedimentary sandstone, with volcanic eruptions occasionally containing columnar basalt in other locations (Bassey et al., 2022). Sandy, structure-less profiles and early-stage laterite are characteristics of old sedimentary soils. In general, the soils are red and contain a lot of iron oxide. They range from clayey-loam to loamy-clay. Their low nutritional status and acidity render them unsuitable for the development of arable crops (Bassey et al., 2022). The average annual temperature on Afi Mountain is 22.2°C, while the average annual rainfall fluctuates between 3,000 and 3,800 mm

(Bassey et al., 2022). According to Balogun (2003), at 7:00 a.m., the average yearly relative humidity is 78%. The tropical high forest vegetation zone is where the majority of the vegetation in the Afi River Forest Reserve is found. The base of the mountain is covered in rainforest. The forest structure eventually transforms into sub-montane flora at elevations of roughly 700 meters above sea level, while yearly bush fires have caused the vegetation to shift into grassland above 500 meters.

Sampling Technique and Data Collection

Sample plots were laid using a systematic line transect; two transects of 1500m in length, separated by at least 500m, were used for this study; sample plots of 50m x 50m in size were laid alternately along each transect at 100m intervals, creating a total of 10 sample plots per 1500m transect and 20 sample plots in the forest reserves (Stanley and Ajayi, 2024). All living trees with dbh ≥10cm were identified and measured in each sample plot.

A Spiegel relascope was used to measure the height of each tree as well as its DBH and other diameters, including the base, middle, and top diameters. The dbh of trees growing on a slope was determined by measuring the tree's uphill side. Crucially, buttresses were not regarded as commercial. Therefore, the equivalent of dbh was measured at a height of 20 cm above the upper limit of the buttresses when they extended more than 1.30 m above the ground surface. As advised by Adekunle et al. (2010), a more representative dbh point was selected, either above or below the breast-height point, in cases where knots or localized deformations occurred at that location. Data Analysis

Basal Area Estimation

The diameter at breast height was used to calculate the Basal Area (AB).

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

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

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

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

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

Stem Volume Estimation

Individual tree volume was calculated using the Newton's formula of Husch*et al.,* (2003); Bassey, *et al.,* (2022) given as:

$V = \frac{h}{6}[A_b + 4A_m + A_t]$ eq.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 mean plot volume was calculated by dividing the total plot volume by the number of sample plots, and the plot volumes were calculated by adding the volumes of each tree in the plot. The mean per plot was then multiplied by the number of sampling units in a hectare to estimate the volume of trees per hectare (Vha) (Stanley and Ajayi, 2024, Adekunle, 2010).**Diameter**

Distribution Models for Screening

Easy Fit software was used to create the models for the diameter distribution, and the diameter probability functions used in this work for the estimation of the diameter distribution areas were listed**:**

Weibull model: Ratkowsky (1983) and Myers (1986) employed the two-parameter Weibull models in their studies.

The models were: $W(t) = \left(\alpha - \beta e^{-kt^m}\right) + \varepsilon$ eq.4

Logistic model: Nelder (1961) and Oliver (1964) employed this model:

$W(t) = \alpha/(1 + \beta e^{-kt}) + \varepsilon$ eq.5

Burr (4P)

$f(x) = \frac{\alpha k\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}}{\beta\left(1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{k+1}}$eq.6

JohnsonS$_B$ Distribution $f(x) = \frac{\delta}{\lambda\sqrt{2\pi z(1-Z)}} \exp\left[-\frac{1}{2}\left(\gamma + \delta \ln\frac{z}{1-Z}\right)^2\right]$ eq.7

Beta Distribution $F(x) = \frac{1}{B(\alpha_1,\alpha_2)} \frac{(x-a)^{\alpha_1-1}(b-x)^{\alpha_2-1}}{(b-a)^{\alpha_1+\alpha_2-1}}$ eq.8

Weibull Distribution $f(x) = \frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1} exp\left(-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)$ eq.9

General Pareto Distribution $f(x) = \frac{1}{\sigma}\left(1 - \frac{\xi(\chi-\mu)}{\sigma}\right)^{\left(-\frac{1}{\xi}-1\right)}$ eq.10

Generalized Gamma 4P Distribution $f(x) = \frac{k(\chi-\gamma)^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)} \exp\left(-\left(\frac{\chi-\gamma}{\beta}\right)^{k}\right)$ eq.11

Lognormal Distribution $f(x) = \frac{1}{x\alpha\sqrt{\pi}} e0.5^{\left(\frac{lnx-\mu}{\sigma}\right)2}$ eq.12

Gamma 3P $f(x) = \frac{x^{\alpha-1}}{\beta\Gamma(\alpha)} \exp\left(\frac{-x}{\beta}\right)$ eq.13

Exponential 2P $f(x) = \lambda e^{-\lambda x}$ eq.14

Erlang 3P $f(x) = \frac{\lambda^k x^{k-1} e^{-\lambda x}}{(k-1)!}$ eq.15

Inverse Gaussian $f(x) = \left(\frac{\lambda}{2\pi x^3}\right)^{1/2} exp\left(\frac{-\lambda(x-\mu)^2}{2\mu^2 x}\right)$ eq.16

Test Statistics for Assessing Diameter Distribution Models

The selection of the best diameter distribution models were based on:

i. Kolmogorov Smirnov
ii. Anderson Darling
iii. Chi-Square

Validation of the Diameter Distribution Models

For models of diameter distribution, the estimated parameter values were entered into the models' Probability Density Function, and the best adjudicated model was used to replace x with DBH. The Student's T-test of Goulding (1997) and one-way analysis of variance were used to compare the results (predicted diameter distribution) with the observed DBH frequency. The diameter distribution of the species in the study was thought to be adequately described by the models that did not demonstrate a significant disparity between the observed and projected DBH.

Aboveground Green Biomass Estimation

The total plot biomass (AGBplot) was created by adding the biomass values that were determined for each tree in a sample. The aboveground biomass estimate per plot (in kilograms) was converted to metric tons by dividing it by 1000. The following formula was then used to convert this to the per hectare estimate (AGBha):

$$AGBper\ ha = \left(\frac{Ah}{Ap}\right) \times AGBplot \qquad \text{eq.17}$$

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, Bassey and Ajayi, 2024).

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.

Aboveground Dry Biomass Estimation

Aboveground dry biomass estimation was calculated from:

$$W = \frac{AGBh \times 0.725}{1000} \qquad \text{eq.18}$$

Where: W= aboveground dry biomass (metric tons)

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

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

Determination of Carbon Sequestration

$$Sc = Wx\ 0.5 \qquad \text{eq.19}$$

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

W= aboveground dry biomass (t ha^{-1}) (Bassey and Ajayi, 2020) and expressed in t/ha.

RESULTS

Growth Characteristics of Afi River Forest Reserve

A total of 1368 unique trees, representing 65 species from 18 different tree families, were measured for breast height, base, middle, and top diameters, as well as overall tree height, as indicated by the results in table 3 below. The average tree volume and biomass were found to be 10.36 m3 and 76.31 kg, respectively, while the mean diameter at breast height (dbh) and total height were measured to be 25.82 cm and 18.5 m, respectively. With a mean volume of 271.249 m3 ha-1 and a mean green biomass of 460.867 tons ha-1 and a mean dry biomass of 334.128 tons ha-1, the estimated mean basal area was 50.29 m2 ha-1.

Table 1: Summary of Characteristics data for Afi 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	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	325.	188.29	409.98	12.865	56.54	-512	-992

biomass (ton ha^{-1})	423

Diameter Distribution Functions, Parameter Estimates and Assessment Criteria

The results in Table 2 showed the parameters for each of the diameter distribution functions connected to each diameter model screened for the forest reserve.

Table 2: Summary of Parameters for the Selected Diameter Functions for Afi Reserve of Cross River State, Nigeria

Forest Reserve	Distribution	a	α_1	α_2	β	B	K	γ	δ	μ
Afi	Log-Logistic (3P)	1.68			9.48	9.76				
	Pearson 5 (3P)	1.93			18.54	7.50				
	Pearson 6 (4P)		17.99	1.94	1.01	7.97				
	Dagum (4P)	1.68			1.11	6.28	41.80			
	Frechet (3P)	1.70			10.42	6.06				
	Lognormal (3P)					9.52			1.01	2.29
	Gen. Pareto						0.27		10.74	11.07
	Inv. Gaussian (3P)					8.84		13.13		16.98
	Burr (4P)	97.94			40.90	-29.93	0.04			
	Gen. Extreme Value						0.41		6.97	17.01

Summary of Goodness of fit for Selecting Distribution Functions in Afi Forest Reserve, Cross River State, Nigeria

The diameter distribution functions in the study area's parameter estimates and evaluation standards were displayed in Table 3. According to the results of the Anderson Darling, Chi-Squared, and Kolmogorov-Smirnov tests, the 10 distributions fit well and are thus suitable for evaluating the diameter distribution in the research region. The tabulated value (0.05) was exceeded by the D-values (Dagum 4P: 0.0368, Burr 4P: 0.04467, Gen. Extreme Value: 0.04716 and Log-Pearson 3P: 0.028, Pearson 5 (3P): 0.03426, Pearson 6 (4P): 0.03465, Frechet (3P):0.0373, Lognormal (3P): 0.04078, Gen. Pareto:0.04102, and Inv. Gaussian (3P):0.04366). The findings also demonstrated that the Log-Logistic of three parameters (3P) was the most adaptable of the distribution functions and, as a result, was thought to be the most effective in determining the Reserve's diameter distribution, as seen in Table 3

Table 3: Goodness of fit for Selecting Distribution Functions in Afi Forest Reserve, Cross River State, Nigeria

Forest Reserves	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
Afi River		Statistic	Rank	Statistic	Rank	Statistic	Rank
	Log-Logistic (3P)	0.028	1	1.2083	1	34.734	1
	Pearson 5 (3P)	0.03426	2	1.487	2	45.536	7
	Pearson 6 (4P)	0.03465	3	1.5091	3	44.926	5
	Dagum (4P)	0.0368	4	1.6583	4	47.621	8
	Frechet (3P)	0.0373	5	1.6651	5	47.695	9
	Lognormal (3P)	0.04078	6	1.7037	6	37.591	2
	Gen. Pareto	0.04102	7	154.02	44	N/A	
	Inv. Gaussian (3P)	0.04366	8	2.2281	7	39.363	3
	Burr (4P)	0.04467	9	2.9096	8	45.206	6
	Gen. Extreme Value	0.04716	10	4.3885	11	43.425	4

Validation of Diameter Distribution Models in Afi Forest Reserve

The diameter distribution models' validation results for the forest reserve were displayed in Table 4. By contrasting the observed and anticipated distributions, the model was validated using the paired T-test. A non-significant difference (P>0.05) was found between the observed values and the projected distribution from the models chosen for the forest reserve (Table 5).

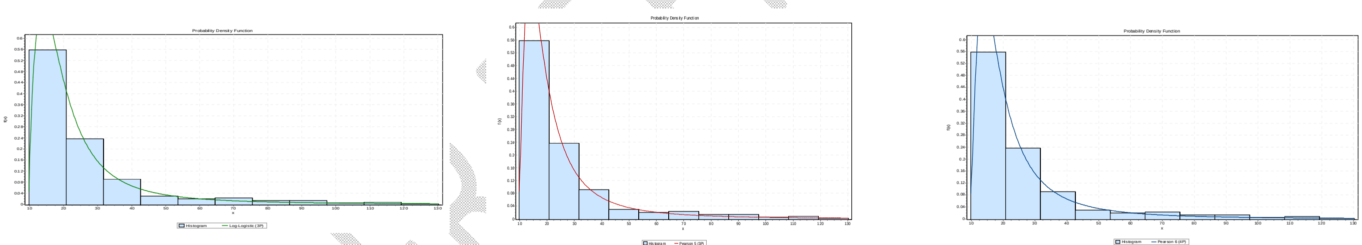
The top three diameter distribution models that may suit the forest reserve's diameter distribution according to the assessment criteria were displayed in Figures 1a, b, and c. Pearson 5 (3P), Log-Logistic (3P), and Pearson 6 (4P) were the top three models.

Table 4: Comparison of the Observed and Predicted Diameter for Log-Logistic (3P) Distribution Model

Dbh Class (cm)	Observed	Predicted
9.8 – 21.5	683.52	765.52
21.6 – 32.0	328.08	328.08
32.1 – 42.5	123.03	136.70
42.6 – 53.9	41.01	68.35
54.0 – 64.8	39.64	41.01
64.9 – 75.5	42.36	39.64
75.6 – 86.2	27.34	27.34
86.3 – 97.5	27.34	27.34
97.6 – 107.5	13.67	6.84
107.6 – 119.8	13.67	13.67
119.9 – 130.5	6.84	6.84

Table 5: T-Test Analysis for the selected Model in the Study Areas

Forest Reserves	Distribution	T-stat	T- crit	P-value	Remark
Afi River	Log-Logistic (3P)	0.11	2.09	0.91	Ns



Figures 1a, b and c: Best three Diameter Distribution Models for Afi River Forest Reserve

Discussion

Modeling the diameter distribution of a forest stand is a vital aspect of forest management and planning (Bassey and Adekunle, 2022). In this study, it was noticed that there was a decline in the quantity of stems per hectare as dbh class increases across reserve. A natural forest's traits were mirrored in the decreases in stems per hectare as the dbh size class rose. According to Adesuyi et al. (2020), trees in an uneven-aged forest develop constantly and have distinct reproductive seasons. This supports their findings. It has been observed that the constant creation of young trees causes age variance, particularly in an undisturbed stand. In an uneven-aged stand, the diameter distribution is hence erratic. Bassey and Adekunle (2022) stressed that as the area of the stand increases, the irregularities tend to even out and the inverse J-shaped diameter distribution becomes apparent.

High positive skewness and peakedness were also noted, indicating that a significant number of trees are concentrated in the lower diameter classes in each reserve (Gadow, 1983). The high positive skewness could also be attributed to the sample plot size (50 m x 50 m) and number of trees per plot (≥60). This finding is consistent with Shiver's (1988) report, which found that most investigation works that look for the diameter distribution in Slash pine plantations would be acceptable with 50 trees per sample plot. Nord-Larsen and Cao (2006) confirm that plot size and spatial structure have an impact on diameter distributions. Furthermore, Nord-Larsen and Cao (2006) stressed that while larger plots can yield a better fit, the quantity of plots should also be taken into account.

Given that it is one of the few surviving rainforest reserves in Nigeria, the high positive skewness may also indicate a healthy stand stock. This implies that, despite ongoing logging, logging in the forest reserve is still very low and that, in order to maintain the reserve, management efforts should be increased. This result also concurred with that of Nurudeen (2011), who found that high skewness and kurtosis were indicative of a right-tailed distribution and a healthy stand stock.

Furthermore, it is possible that the reserve's relatively low level of encroachment contributed to the higher aboveground biomass than the values found in previous studies of tropical rainforest ecosystems in Nigeria (e.g., Adekunle et al., 2004 who reported 181.36 m3/ha in Shasa Forest Reserve; 227 m3/ha in Ala Forest Reserve; 91.71 m3/ha in Omo Forest Reserve; and Adekunle and Olagoke, 2008 who reported 262.36 m3/ha). The higher values found in this study suggest that, as ITTO (2011) also reports, the forest reserve is likely among the richest remaining tropical rainforests in Nigeria.

Conclusion

Diameter distribution information is pertinent for making informed management decisions on product specification and general management of the forest. Also, modeling of forest stand structure is crucial in predicting forest development and yield determination of product specification by distribution of trees into diameter classes. Trees are categorized into various diameter classes to help prescribe silvicultural treatments like pruning, thinning, and selective harvesting for the forest ecosystem's overall sustainable management. In order to prescribe silvicultural treatments and harvesting schedules that will maximize efficiency, it is therefore beneficial in forest management to use the proper statistical distribution tool to forecast the state of a forest stand. Thus, this study forecasted the diameter distribution in the unmanaged uneven-aged stand of the Afi Forest Reserve. The main threats to the forest reserve's sustainability were found to be illegal logging, a lack of permanent sample plots, out-of-date conservation laws, and a lack of community involvement in the reserve's conservation. Biomass analysis is a crucial component of the carbon cycle, particularly carbon sequestration, and it is increasingly being used to help quantify pools and fluxes of greenhouse gases (GHG) from the terrestrial biosphere linked to changes in land use and land cover.The diameter distribution models developed in this research study would serve as a reference point for diameter distributions models for uneven-aged stands in Cross River State as well as a tool for effective reserve management. As a result, this study established the reserve's carbon potentials for carbon trade and site productivity.

Recommendations

1. The Cross River State Forestry Commission should use the fitted models to monitor the reserve more effectively and implement better management techniques.

2. Extensive research utilizing parameter recovery and prediction techniques, using the data from this study as a basis, ought to be conducted throughout the research region.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

References

Adedeji, E.T. Adekunle V.A.J. Adeagbo D.O. (2024). Fitting diameter distribution for Gmelina arborea (roxb.) stands in Omo Forest Reserves, South Western Nigeria. *Journal of Research in Forestry, wildlife & Environment*, 16 (1): 152 – 159.

Adekunle, V.A.J., Akindele S.O. and Fuwape J.A. (2004): Structure and yield models of tropical lowland rainforest ecosystem of southwest Nigeria, *Food, Agriculture and Environment* 2 (2) 395-399.

Adekunle, V.A.J and Olagoke A.O (2008): Diversity and biovolume of tree species in natural forest ecosystem in the Bitumen Producing area of Ondo State, Nigeria: A baseline study, Biodiversity and Conservation 17 -27

Adekunle, VAJ, Olagoke AO, Ogundare LF. (2010). Rate of timber production in a Tropical Rainforest Ecosystem of Southwest Nigeria and its implications on Sustainable Forest Management.Journal of Forestry Research. 21: 225–230.

Adesoye, P.O (2002). Integrated system of forest stand models for *Nauclea diderrichi* in Omo forest reserve, Nigeria. Ph.D thesis, Department of Forest Resources Management, University of Ibadan, Nigeria.174p.

Adesuyi FE, Akinbowale AS, Olugbadieye OG & Jayeola K (2020) Fitting non-linear models for tree volume estimation in strict nature reserve, South-West, Nigeria. *Tropical Plant Research* 7(1): 6–13]

Balogun, O.Y., (2003): Senior Secondary School Atlas, 2nd edition, p: 19. Longman Publishers, Lagos.

Bassey SE, Ajayi S. Modeling of aboveground tree stand-level biomass in Erukot Forest of Oban Division, Cross River National Park, Nigeria. J Agric For Soc Sci (JOAFSS). 2020;18(1). ISSN: 1597-0906.

Bassey SE, Ajayi S, Igbang KS. Non-linear models for tree volume and above ground biomass estimation in Afi River Forest Reserve, Cross River State, Nigeria. *J Res For Wildl Environ*. 2022;14(3):142–9.

Bassey S. E and Adekunle V. A. J (2022). Developing Diameter Distribution Models in Ukpon Rainforest Reserve of Cross River State, Nigeria. *Journal of Research in Forestry, Wildlife and Environment,* 14(2):84-94

Brown, S. (1997). Estimating biomass and biomass change of tropical forests. Forest Resources Assessment Publication. Forestry Papers 134. *FAO, Rome,* 55 pp.

Cairns, M. A., L. Olmsted, J. Gradanos & J. Argaeg. (2003). Composition and aboveground tree biomass of dry semi-evergreen forest on Mexico's Yucatan Peninsula. *Forest Ecology and Management* 186: 125-132.

Chavan, B. L. and Rasal (2012). Total Sequestered Standing Carbon Stock in Selective Tree Species Grown in University Campus. Aurangabad Maharashtra, India. International Journal of Engineering Science and Technology 2(7): 3003 3007pp.

Gadow, K. V. (1983). Fitting distributions in P*inus patula* stands. *South African Forestry Journal*, 20-29.

Goulding, C.J. (1979): Validation of Growth Models Used In Forest Management, New Zealand Journal of Forestry. Vol. 24 No 1: 108 - 124.

Husch, B., T.W. Beers and J.A. Kershaw Jr., (2003): *Forest Mensuration.* 4th Edn., John Wiley and Sons, Inc., New Jersey, USA., pp: 949.

ITTO. (2011): Status of tropical forest mangemenent. *Technical series* 38.P.420.

Nord-Larsen T & Cao QV (2006). A Diameter Distribution model for Even-aged Beech in Denmark. *Forest Ecology and Management* 231: 218–225.

Nurudeen, T.A (2011). Non linear regression models for volume estimstion in *Gmelina arborea* (Roxb) stands at Oluwa forest reserve South western Nigeria. *M.sc Thesis submitted to the Department of Forest Resource Management, University of Ibadan, Nigeria* 78p

Shiver, B. D. (1988). Sample Sizes and Estimation Methods for the Weibull Distribution for Unthinned Slash Pine Plantation Diameter Distributions. *Forest Science* 34: 809-814.

Pandey of Envisat ASAR data for woody biomass assessment. *Tropical Ecology* 51: 117-124.

Saatchi, S. S., N. L. Harris, S. Brown, M. Lefsky, E. T. A. Mitchard, W. Salas, B. R. Zutta, W. Buermannb, S. L. Lewisg, S. Hagen, S. Petrova, L. Whiteh, M. Silmani & A. Morel. (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences USA.* doi: 10.1073/pnas.1019576108.

S. E, Bassey, and Ajayi, S. 2024. "Non-Linear Models for Tree Aboveground Biomass and Volume Estimation in Agoi- Ibami Forest Reserve, Cross River State, Nigeria". *Asian Journal of Research in Agriculture and Forestry 10 (4):376-86.* https://doi.org/10.9734/ajraf/2024/v10i4343.

Wani, N., A. Velmurugan & V. K. Dadhwal. (2010). Assessment of agricultural crop and soil carbon pools in Madhya Pradesh, India. *Tropical Ecology* 51: 11-19.