Diameter Distribution Model for *Nauclea diderrichii* (D. Wild) Merr. Plantation at the Forestry Research Institute of Nigeria (FRIN.), Ibadan, Oyo State, Nigeria

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ABSTRACT

Modeling stand structure is paramount as it furnishes forest managers with fundamental data for forecasting forest estate growth and yield. Surprisingly, limited attention has been devoted to utilizing probability distribution functions for characterizing the stem diameter of indigenous species in Nigeria. The study focused on modeling the diameter distribution of *Nauclea diderrichii* plantation at the Forestry Research Institute of Nigeria.

Data was collected from stands established in 2011. Simple Random Sampling was used to establishing 10 plots of 20m by 20 m in size. Stem diameter of all *Nauclea diderrichii* trees with diameter ≥ 10 cm in the plots were enumerated. Three distribution functions: 2p Weibull, 3p Weibull and Lognormal were fitted to the data set. Maximum likelihood Estimation method was adopted for fitting the three distribution functions. The determination of the most suitable distribution was done using the Anderson-Darling and Cramer-von Mises tests.

The results indicated that the Lognormal distribution exhibited the best fit, with Cramer-von Mises and Anderson-Darling values of 0.0359 and 0.2175, respectively. The 3P Weibull distribution had values of 0.1125 and 0.6859, while the 2P Weibull distribution had values of 0.2771 and 1.762, respectively. The Lognormal distribution using the Maximum Likelihood Estimator was recommended as the most suitable model for describing the stem diameter of *Nauclea diderrichii* in the study area.

(Keywords: *diameter distribution model, diameter class distribution, height class distribution, Nauclea diderrichii, plantation*)

INTRODUCTION

Sustainable management of natural resources requires large amount of supporting information especially when it involves managing forest for production of valuable materials. The estimation of current of growth variable such as timber volume which are not easy to measure and estimate for future growth values are essential (Nurudeen, *et al*., 2017). As such, one of the main concerns of forest managers is being able to measure the quantity of trees in various diameter classes within a stand. This is important since the diameter size affects the industrial uses of the timber and the price of the products

Forest stand models serve as abstractions of the natural dynamics encompassing the growth, mortality, and various changes in stand composition and structure. These models prove highly effective as valuable resources and management tools, providing essential information about stand structure, density, and stability. Forest managers and planners depend on developing effective and precise models to forecast forest growth and products. The tree distribution model is a crucial technique for characterizing tree populations and forest stands. They aid in estimating forests' worth, forecasting tree growth, scheduling harvesting operations, and increasing production (Burkhart and Tome, 2012).

One commonly used method to describe stand structure is by examining the diameter distribution, which represents the number of trees falling within various diameter classes. Modeling the diameter distribution involves the selection of an appropriate function and an estimation method to obtain the most accurate parameters for the chosen function (Ogana and Abwage, 2018).

Forest managers rely on this data to make informed decisions about forest stand management. It provides a wealth of information, ranging from the types of timber available to estimates of carbon stocks and insights into forest biodiversity (Kuuluvainen, *et al*., 1996).

Diameter distributions are a well-established and commonly employed method for representing the structure of forest stands. They offer a valuable means of quantifying tree characteristics, encompassing physical, physiological, and growth-related processes. By tracking diameter distributions over time, forest managers can establish relationships between these parameters and stand age or density, providing insights into stand dynamics. Estimating stand volume characteristics relies on diameter distribution data in conjunction with tree height and volume models.

Additionally, diameter distribution techniques play a vital role in assessing growth and yield in forestry management (Burges, *et al*., 2005). At the species level, when diameter distribution are assessed, they play effective role in providing vital information on regeneration strategies, effective silvicultural treatment for harvesting regimes for any forest stand and stand yields have been predicted based on diameter distribution using Probability Density Function (PDF) (Poudel and Cao, 2013).

Over the past three decades, a range of Probability Density Functions (PDFs) such as the normal, log-normal, gamma, beta, Johnson's SB, and Weibull distributions have been frequently employed to describe the frequency distributions of diameters within forest stands. This variety of PDFs has been instrumental in characterizing and understanding forest stand structures (Clutter, 1983).

Nauclea diderrichii is a significant indigenous tree species known for its versatile applications, including medicinal and food uses. However, despite its adaptability, Ogundipe, *et al.* (2018) found that the plantations of this species in Nigeria, particularly at the Forestry Research Institute of Nigeria (FRIN) in Ibadan, lack sustainable management practices. Insufficient data exists regarding the current growth rate and future production expectations of *Nauclea diderrichii* in these plantations.

While previous studies have explored various aspects of *Nauclea diderrichii* plantations, such as growth characteristics and biomass assessment, the development of a diameter distribution model for this species has not been extensively documented. Hence, the primary aim of this study is to establish a robust diameter distribution model for *Nauclea diderrichii* plantations at Forestry Research Institute of Nigeria (FRIN) to enhance the effective management of these stands.

The study aims to achieve specific objectives, which involve assessing both the diameter and height distribution within the stand and subsequently creating models for the diameter distribution.

It is vital to underline the value of modeling stand structure, as it has proven highly effective in yielding valuable insights into tree distribution and sizes (Ige and Adedapo, 2021). This model will provide crucial insights into the anticipated growth and yield of the plantation, facilitating more effective management practices and the application of silvicultural treatments.

METHODOLOGY

Study Location

The research was conducted at the Forestry Research Institute of Nigeria (FRIN) in Ibadan, Oyo State. The study area is situated between latitudes 03°51' 20" E and 03°51' 43" E and longitudes 07°23' 18" N and 07°23' 43" N (Nurudeen et al., 2017). (Figure 1)

Climate: The climate in this region exhibits distinct dry and wet seasons. The dry season spans from November to March and is characterized by the dry Harmattan wind.

Conversely, the wet season typically occurs from April to October, accompanied by heavy winds and occasional thunderstorms. The average annual rainfall is 1548.9 mm, most falling within 90 days. This rainfall pattern is bimodal, with peaks in June and July and another in September through October. Ariwaodo, *et al*. (2012) reported an average annual rainfall of 420.06 mm over approximately 109 days.

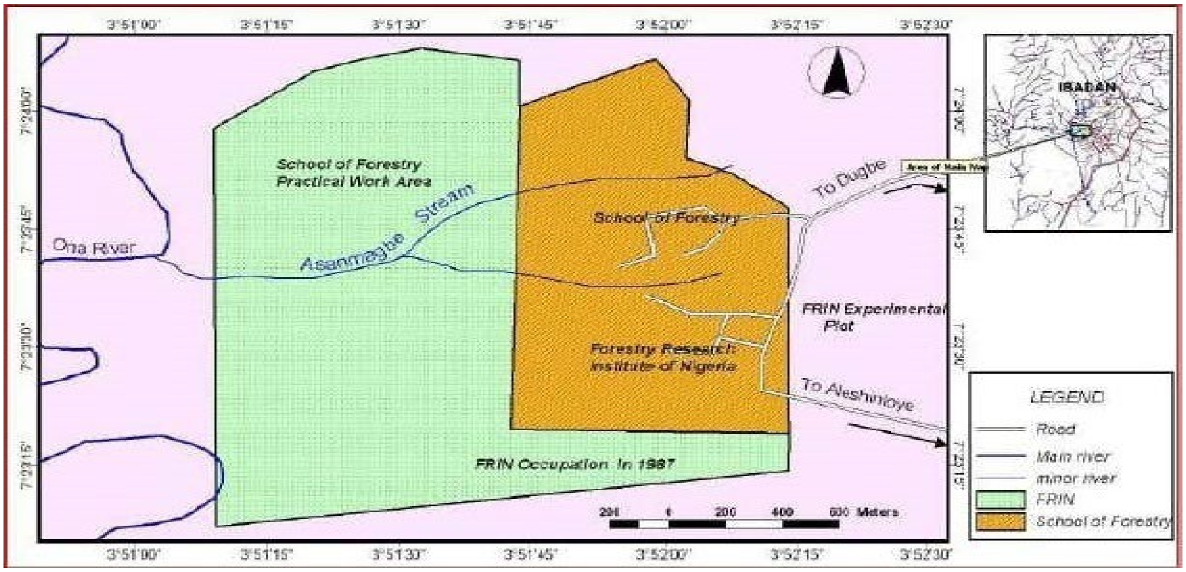

Figure 1: Map of Study Area.

The relative humidity level averages 74.6%. Maximum and minimum temperatures average 39°C and 24.3°C, respectively, with a daily relative humidity of around 71.9%, as reported (Olunloyo, *et al.*, 2021).

This area's vegetation surrounding a significant watershed stream can be considered a near-natural plant community with no signs of anthropogenic disturbance. The region's topography is undulating, with underlying ferruginous sandy loam soils resting on an undifferentiated pre-Cambrian foundation of complex crystalline rocks (Ariwaodo, *et al.*, 2012).

Sampling Procedure and Data Collection: A single age series of *Nauclea diderrichii* plantation established in 2011 was selected. To gather data, a Simple Random Sampling method was employed, resulting in the selection of 10 plots, each measuring 20m by 20m in size. Within these selected plots, data were collected on parameters including Diameter at breast height (Dbh) in centimeters, total height in meters, which were subsequently used to calculate basal area in square meters and volume in cubic meters. All trees within each plot were identified and measured, and information regarding the total number of species in each selected plot was recorded.

Measurement of Tree Growth Variables: Tree growth variables assessed include:

1. **Diameter at Different Heights**: This includes measuring the tree's diameter at breast height, base, middle, and top. The diameter at breast height was measured using a diameter tape, while the diameter at the base and top were measured using a Spiegel relaskop.

2. **Total Size**: This represents the vertical distance between the base of the tree stem (ground level) and the topmost tip of the tree, and it was measured using a Haga altimeter.

DATA ANALYSIS

Basal Area Computation: The basal area of individual trees was computed using specific methods that will be described further in the study.

$$BA = \frac{\pi Dbh^2}{4}$$

Where: BA = basal area (m^2); Dbh = diameter at breast height.

Tree Volume Estimation: Tree volume estimation was carried out utilizing Newton's formula.

$$V = \frac{\pi H}{24}(D_b^2 + 4D_m^2 + D_t^2)$$

Where: V = stem volume; H = total tree height; Db = tree diameter at the base; Dm = tree diameter at the middle; Dt = tree diameter at the top.

DIAMETER DISTRIBUTION MODELS

2 and 3 Parameters Weibull and Lognormal distributions were adopted, all the distribution were estimated by Maximum Likelihood Estimator (MLE)

Weibull Distribution

Probability Density Function: For 2P

$$= \frac{c}{b}\left(\frac{x}{b}\right)^{c-1} \exp\left[-\left(\frac{x}{b}\right)^{c}\right]$$

For 3P:

$$= \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} \exp\left[-\left(\frac{x-a}{b}\right)^{c}\right]$$

Cumulative Distribution Function

The Weibull cumulative distribution function (Cdf) is obtained by the integration of the PDF. It is expressed as:

For 2P: $f(x) = 1 - \exp\left[-\left(\frac{x}{b}\right)^{c}\right]$

For 3P: $f(x) = 1 - \exp\left[-\left(\frac{x-a}{b}\right)^{c}\right]$

Location assumed to be Zero in 2P Weibull

Where (x) is the relative frequency of tree; *x* represents the continuous random variable (i.e., tree diameter); c is the shape parameter (c> 0); b represents the scale parameter (b > 0) and a is the location parameter.

For Parameter Estimation Method Used Maximum likelihood (ML):

$$\frac{\sum_{i=1}^{n}(x_i)^c \ln(x_i - a)}{\sum_{i=1}^{n}(x_i - a)^c} - \frac{1}{c} = \frac{1}{n}\sum_{i=1}^{n}(x_i - a)$$

Statistics Test for Models

Anderson Darling (A-D) and Cramer-von Mises (w^2) were used as goodness of fit to test the consistency of the diameter distribution models. The smaller the Statistic value, the better the distribution.

$$A - D = -n - \frac{1}{n}\sum_{i=1}^{N}(2_i - 1).\left[lnF(x_i) + ln\left(1 - F(x_{n+1-i})\right)\right]$$

$$\omega^2 = \sum_{i=1}^{n}\left\{\hat{F}(x_i) - \frac{(i - 0.5)}{n}\right\}^2 + \frac{1}{12n}$$

Where *F(xi)* and *F0(xi)* are the observed cumulative frequency distribution and theoretical cumulative frequency distribution, respectively; *xi* (in cm) represents the diameter (*i* ranged from 1 to n); *n* is the number of observations; $f(xi)$ and $f0(xi)$ are the observed and predicted relative frequency of trees, respectively.

RESULTS AND DISCUSSION

Table 1 shows the descriptive analysis of the growth variable used.

The mean Dbh is 19.697 cm, suggesting that, on average, the trees in the forest stand have a moderate diameter with a relatively high standard deviation (9.284 cm) indicating a considerable variability in tree diameters. The mean Db is 27.769 cm, indicating a larger diameter at the base compared to Dbh. The higher standard deviation (12.723 cm) implies a wide range of tree base diameters.

Table 1: Descriptive Analysis for the Inventoried Data.

Stats	Dbh (cm)	Db (cm)	Dm (cm)	Dt (cm)	Ht (m)	BA (m^2)	Vol. (m^3)
Mean	19.697	27.769	12.993	8.893	11.328	0.037	0.255
Std E	0.690	0.946	0.519	0.410	0.263	0.003	0.021
Std D	9.284	12.723	6.985	5.518	3.536	0.037	0.287
Min	4.137	6.365	3.000	2.000	3.000	0.001	0.006
Max	52.196	82.750	42.000	34.000	20.000	0.214	1.891

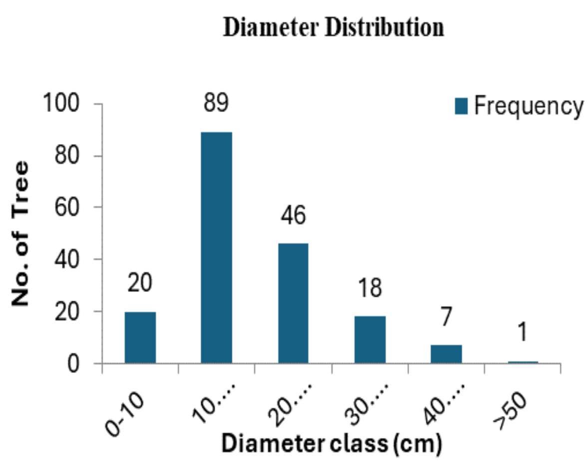

Figure 2: Diameter Class (cm) Distribution of the Plantation.

The diameter class distribution in the plantation is depicted in the figure above. Many trees fall within the 10.1-20 cm diameter class, whereas the 50 cm and above class has the lowest representation with only one tree. This distribution suggests that trees with a breast height (Dbh) diameter between 10 cm and 20 cm are the most abundant in the plantation.

In the height distribution, the 10.1-20 meter class exhibited the highest tree count, whereas the 0-5 meter class had the lowest, with just 5 trees. This indicates that the majority of trees in the plantation have a total height ranging from 10 meters to 20 meters.

Table 2 shows the parameter estimation of 2P, 3P Weibull and Lognormal distribution where 2P: b=22.3101, c =2.2622; Lognormal: b=2.8736, c =0.4684; 3P: a =3.8306, b =17.8762, c =1.7987.

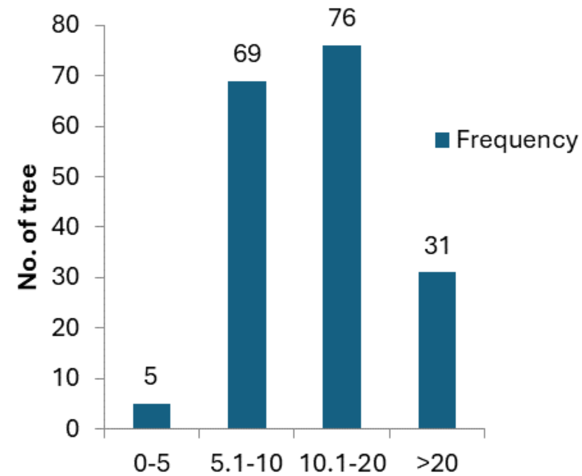

Figure 3: Height class (m) Distribution of the Plantation.

Table 2: Parameter Estimation for 2P, 3P Weibull and Lognormal Distribution by Maximum Likelihood Estimator (MLE).

Distributions	Parameter Estimates		
	A	B	C
Weibull 2P		22.3101	2.2622
Lognormal 2P		2.8736	0.4684
Weibull 3P	3.8306	17.8762	1.7987

Where: a= location, b = scale and c = shape parameters of the distribution.

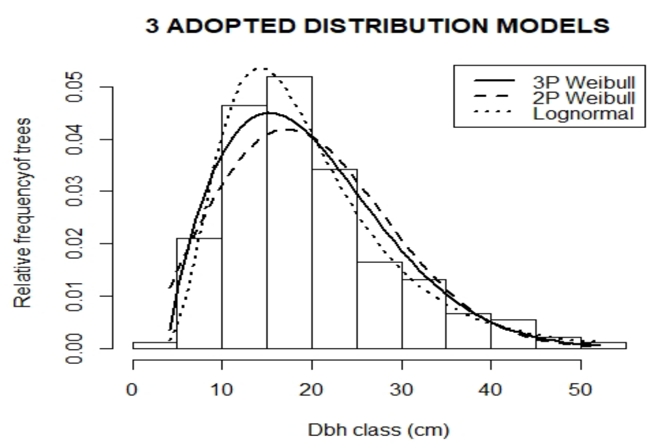

Figure 4: Distribution Models.

Distribution Models

Figure 4 shows the pattern of the diameter distribution within the plantation as having a bell-shaped or normal curve. There are fewer trees at both the lower and bigger diameter ranges in this distribution, with a considerable number of trees clustered within the middle diameter classes. This indicates that there are enough trees in the lower class Dbh class to replace the trees in the upper Dbh class when they are harvested. The results are consistent with studies by Bobo, *et al*. (2006) and Boubli, *et al*. (2004). Ige, *et al*. (2013) in the Nigerian Onigambari Forest Reserve and Hashemi (2011) in the North of Iran Forest observed similar findings.

The diameter distribution also shows a positive skewness. This indicates good stock, which may indicate very little logging and a need for more intensive plantation management. This result is consistent with that of Nurudeen (2011), who found that high skewness and Kurtosis were signs of a well-stocked stand and a right-tailed distribution, respectively. Adekunle (2002) reported that the Ala and Omo Forest Reserves in Nigeria have a favorable skewness distribution pattern. This implies that the plantation is still growing, which is an indicator of the health and strength (Jimoh, *et al*., 2012).

Furthermore, the graph compares the observed diameter distribution based on inventory data and the predicted diameter distribution using three models: 3P Weibull, 2P Weibull, and Lognormal. The empirical and theoretical cumulative, or the observed and expected frequency, do not differ statistically, as seen by the graphs of the observed and estimated functions of the Dbh of the distribution functions (Figure 4).

The visual analysis depicted in Figure 4 reveals that the 2P and 3P Weibull models tend to slightly underestimate the relative frequency of trees compared to the observed distribution. In contrast, the Lognormal distribution tends to overestimate it.

STATISTICAL TEST FOR MODEL EVALUATION

Table 3 shows the result of the summary goodness of fit for the diameter distributions functions used for Forestry Research Institute of Nigeria *N. diderrichii* plantation. That is that the critical values of the tests used to determine the distribution function. The Anderson-Darling statistic (A-D) and Cramer-von Mises (w^2) statistics were used. The critical values of the test of statistics for assessing criteria in describing the diameter distribution of selected observed and estimated probability distribution function were used to validate the output of the distribution models. The performance of each of the diameter distribution model was assessed to evaluate the performance of the diameter distribution function that best predict the diameter structure. A lower w^2 value generally indicates a better fit.

Table 3: Statistical Test for Model Evaluation.

Model	Statistical Test	
	An	w^2
2P Weibull	1.762	0.2771
Lognormal	0.2175	0.0359
3P Weibull	0.6859	0.1125

Table 3 shows revealed that Lognormal distribution has lower statistical values of An and w^2 compared to other distribution which followed by 3P Weibull distribution. The w^2 value of 0.0359 indicates a strong goodness of fit for the Lognormal distribution while w^2 value of 0.1125 indicates satisfactory goodness of fit for 3P and w^2 value of 0.2771 indicates a reasonable goodness of fit for 2P distributions. The results of the goodness-of-fit analysis indicate that the Lognormal distribution model when using the Maximum Likelihood Estimator, yielded lower statistical values for the statistics compared to the 2P and 3P Weibull distributions. This suggests that the Lognormal distribution is more suitable for predicting tree diameters based on the inventory data.

This finding contradicts a prior study conducted by Chukwu, *et al.* (2017), which favored the 3P Weibull distribution as the best fit for crown diameters of tree species in the Shasha Forest Reserve, Osun State, Nigeria. This discrepancy in findings may be attributed to differences in the stand structure of the two study areas.

CONCLUIONS

The study involved the analysis and testing of three different diameter distribution models. The diameter distribution model was successfully estimated using the graph of probability density unction that showed that expected frequencies in each diameter class. The findings unequivocally demonstrate that the Lognormal distribution outperforms the other two models investigated in this study. The findings suggest that the configuration of the stand closely mirrors a bell-shaped distribution, a typical characteristic observed in plantation structures.

The findings of the study reveal that the best diameter distribution model for the FRIN *Nauclea diderichii* plantation is the lognormal distribution model with the Maximum Likelihood Estimator. Furthermore, it is recommended to explore alternative models and employ different estimation methods in subsequent research to enhance the comprehensiveness of the analysis.

REFERENCES

1. Adekunle, V.A.J. 2002. "Inventory Techniques and Models for Yield and Tree Species Diversity Assessment in Ala and Omo Forest Reserves". Ph.D. Thesis, South West, Nigeria, Pp:170

2. Adekunle, V.A.J. 2007. "Non-Linear Regression Models for Timber Volume Estimation in Natural Forest Ecosystem, Southwest, Nigeria". *Research Journal of Forestry.* 1(2): 40-54.

3. Ariwaodo. J.O., K.A. Adeniji, and O.D. Akinyemi. 2012. "The Vascular Flora on Asamagbe Stream Bank, Forestry Research Institute of Nigeria (FRIN) Premises, Ibadan, Nigeria". *Annals of Research*. 3(4): 1757-1763.

4. Bobo, K.S., M. Waltert, N.M. Sainge, J. Njokagbor, H. Fermon, and M. Muhlenberg. 2006. "From Forest to Farmland: Species Richness Patterns of Trees and Understory Plants along a Gradient of Forest Conversion in Southwestern Cameroon". *Biodiversity and Conservation* 15; 4097-4117.

5. Boubli, J.P., J. Eriksson, S. Wich, G. Hohmann, and B. Fruth. 2004. "Mesoscale Transect Sampling of Trees in the Lomako-Yekokora Interfluvium, Democratic Republic of the Congo". *Biodiversity and Conservation*. 13: 2399-2417.

6. Burkhart, H.E and M. Tome. 2012. "Modelling Forest Trees and Stands". Springer Science and Business Media: Berlin, Germany.. https://doi.org/10.1007/978-90481-3170-9

7. Burgess, D., C. Robinson, and S. Wetze. 2005. "Eastern White Pine Response to Release 30 Years after Partial harvesting in Pine Mixed Wood Forests". *Forest Ecology Management,* 209, 117–129.

8. Chukwu, O., I.B. Chenge, and J.U. Ezenwenyi. 2017. "Tree Crown Distribution for Wildlife Management of Shasha Forest Reserve, Nigeria". *Nigerian Journal of Wildlife Management*, 1(1): 86 – 91.

9. Clutter, J.L. J.C. Fortson, L.V. Pienaar, G.H. Brister, and R.L. Bailey. 1983. *Timber Management: A Quantitative Approach*. John Wiley and Sons: New York, NY.

10. Hashemi, M. 2014. "Forest Management Planning to Increase Biodiversity in Woodland (Case Study: Forests of Northern Iran)". *Journal of Biodiversity and Environmental Science*. 5(6): 302-311.

11. Ige, P.O. and S.M. Adedapo. 2021. "Modelling Diameter Distributions of *Nauclea diderrichii* (De Wild) Merr. Stands with Gamma and Weibull Functions in Southwest, Nigeria". *World Scientific News*. 160: 247-262

12. Ige, P.O., G.O. Akinyemi, and E.A. Abi. 2013. "Diameter Distribution Models for Tropical Natural Forest Trees in Onigambari Forest Reserve". *Journal of Natural Science Research*. 3 (12): 14-22.

13. Kuuluvainen, T., M.N. Leinonen, and A. Penttinen. 1996. "Statistical Opportunities for Comparing Stand Structural Heterogeneity in Managed and Primeval Forest: An Example from Boreal Spruce Forest in Southern Finland". *Silva Fennica*. 30(2-3):315-328.

14. Nurudeen, T.A. 2011. "Non- Linear Regression Model for Volume Estimation in *Gmelina arborea* (Roxb) stand at Oluwa Forest Reserve, Southwestern, Nigeria". M.Sc. Thesis submitted to the Department of Forest Resource Management, University of Ibadan: Ibadan, Nigeria. 78pp.

15. Nurudeen, T.A, J.K. Abiola, K.D. Salami, W.A. Erinle, and W.A. Olaniyi. 2014. "Regression Model of Tree Volume Prediction in Stands of *Tectona grandis* (Linn) at Federal College of Forestry, Jericho, Ibadan, Oyo State Nigeria". *Science Journal of Agricultural Research and Management*, ISSN: 2276-8572

16. Ogana, F.N., and N.E. Ekpa. 2020. "Modeling the Non-Spatial Structure of *Gmelina arborea* Roxb Stands in the Oluwa Forest Reserve, Nigeria". *Forestist*, 70: 133-140. DOI: 10.5152/forestist.2020.19037

17. Ogana F.N. and W.D. Abwage. 2018. "Effect of Plot Dimension on Weibull Parameters".

In: *Forests and Forest Products: Keys to Environmental Conservation and National Development*, A.D. Isah, S.B. Shamaki, V.A.J. Adekunle, and A.G. Bello, Editors. Proceedings of the 6th Biennial National Conference of the Forests and Forest Products Society. Held at Usman Danfodiyo University, Sokoto, Nigeria 23rd - 27th April, 2018 pp 1-8

18. Ogundipe, O.C., J.S.A. Osho, and O.D. Olukunle. 2018. "Modeling Diameter Distributions of *Nauclea diderrichii* stands in Omo Forest Reserve, Nigeria with Johnsons SB". *Agricultural Research and Technology*. 18(3): 149-154.

19. Olunloyo, O.O., D.E. Ibiyeye, O.I. Owolola, R.T. Afolabi, and D.A. Ezekiel. 2021. "Estimating Tree Height and Volume of *Gmelina arborea* and Three other Tree Species in Plantations of South-West, Nigeria". *Nigeria Agricultural Journal*. 52(2): 209-214

20. Poudel, K.P. and Q.V. Cao. 2013. "Evaluation of Methods to Predict Weibull Parameters for Characterizing Diameter Distributions". *Forest Science* 59: 2:243-252.

21. Shamaki, S. and S.O. Akindele. 2014. "Diameter Distribution Models for Seven-Year-Old Stand of *Tectona grandis* in Nimbia Forest Reserve, Nigeria". *Nigerian Journal of Forestry*. 44(2): 54-61.

22. Vanclay J.K. 1994. *Modelling Forest Growth and Yield: Applications to Mixed Tropical Forests*. CAB International: London, UK.

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