Stand Diameter Distribution Modelling of a Savanna Woodland in North-Central Nigeria

Chenge, I.B.[1]; * Japheth D.H. [2], Shima, D.D.[1]

[1.] Department of Forest Production and Products, College of Forestry and Fisheries, Joseph Sarwuan Tarka University, Makurdi, Nigeria
[2.] Department of Forestry and Wildlife Technology, Federal University of Technology, Owerri, Nigeria
daujaph@gmail.com

Abstract: This study modelled the stand diameter distribution of a Guinea savanna woodland located in North-Central Nigeria. Diameter at breast height (DBH) data were obtained from a sample of 119 live trees in the woodland. Tree diameters ranged from 4.6 cm to 41.1 cm with a mean of 10.3 cm (SD = 5.4 cm) and exhibited a positively skewed distribution (skewness = 2.3; kurtosis = 10.0), indicating dominance of small-sized stems. Some probability density functions, including Weibull, Gamma, Lognormal, Normal, Cauchy, Exponential, and Logistic, were fitted to the diameter data to evaluate their suitability for describing stand structure. Model performance was evaluated using Kolmogorov–Smirnov, Cramér–von Mises, and Anderson–Darling goodness-of-fit tests. The Lognormal distribution provided the best overall fit, followed by the Gamma and Logistic distributions. The results indicate a structurally heterogeneous woodland dominated by smaller diameter classes with few large individuals influencing overall stand structure. This study demonstrates the suitability of probabilistic diameter distribution models for describing woodland stand structure and provides baseline information to support sustainable management of the woodland.

[Chenge, I.B., Japheth D.H., Shima, D.D. Stand Diameter Distribution Modelling of a Savanna Woodland in North-Central Nigeria. *Life Sci J 2025;22(12):15-28]. ISSN 1097-8135 (print); ISSN 2372-613X (online)*. http://www.lifesciencesite.com. *02. doi:*10.7537/marslsj221225.02

Keywords: Stand structure, Tree diameter distribution, Tropical woodland, Probability distribution models, Lognormal distribution

1. Introduction

Guinea savanna woodlands constitute an important ecological and socio-economic component of tropical landscapes in sub-Saharan Africa. These woodlands provide ecosystem services such as fuelwood, non-timber forest products, carbon storage, and biodiversity conservation, while also supporting local livelihoods. Despite their importance, quantitative information on stand structure, particularly tree diameter distribution, is limited for many Guinea savanna woodlands in Nigeria.

Diameter distribution modelling is a fundamental tool for understanding forest stand structure, growth dynamics, and management potential. Tree diameter distributions provide insights into regeneration status, productivity, biomass accumulation, and yield potential, and they are widely applied in forest management planning, including harvesting regulation, silvicultural decision-making, and sustainability assessments. The shape of diameter distributions reflects underlying ecological processes such as recruitment, growth, and mortality.

Early observations by De Liocourt (1898) identified the characteristic reverse J-shaped diameter distribution of uneven-aged forests, often described using negative exponential functions. Subsequent studies have shown that different probability distributions—including Weibull, Gamma, Lognormal, Normal, Logistic, and related functions—can adequately describe tree diameter structures depending on stand condition, age structure, and disturbance history. While the Weibull distribution is widely applied due to its flexibility, other distributions have been found to outperform it in heterogeneous or disturbed tropical woodland systems

The idea of tree distribution of modelling tree-diameter can be traced back to the observation made by DeLiocourt (1898) of a reverse J-shaped shape of uneven-aged forests. The negative exponential model was proven useful in further research (Lorimer, 1980; Leak, 1996). Subsequent studies have shown that different probability distributions, including Weibull, Gamma, Lognormal, Normal, Logistic, and related functions, can adequately describe tree diameter structures depending on stand condition, age structure, and disturbance history (Bailey & Dell, 1973; Husch *et al*., 2003; Ogana & Itam, 2016). While the Weibull distribution is widely applied due to its flexibility, other distributions have been found to outperform it in heterogeneous or disturbed tropical forests (Lykke & Svensson, 2002; Liu *et al*., 2002; Adekunle *et al*., 2013)

Given the limited structural information available for Guinea savanna woodlands in North-Central Nigeria, there is a need to evaluate probability distribution models to accurately describe their diameter. This study, therefore, aims to characterize the stand diameter structure of a Guinea savanna woodland in North Central Nigeria and identify the probability distribution function that best fits the observed tree diameter distribution.

2. Materials and Methods

Location of the Study

This study was conducted in the Saint Thomas Aquinas Seminary woodland located in Makurdi, Nigeria, within the Guinea Savanna ecological zone. The study area lies between latitudes 7°13′00″ N and 7°13′20″ N, and longitudes 8°32′00″ E and 8°32′20″ E, covering an area of approximately 25.88 ha. The climate of the area is characterized by a distinct wet and dry season. The rainy season typically extends from April to November, while the dry season occurs between December and March. Mean annual temperature ranges from 28.2 to 32.0 °C, and relative humidity varies between 40% and 85%, with lower values during the early dry season.

Data Collection

A systematic sampling design was employed for data collection. Ten square sample plots measuring 50 m × 50 m (0.25 ha) were established within the woodland. Plot locations were determined by overlaying a systematic grid at 100 m intervals on the woodland map using GIS software. The geographic coordinates of each plot were extracted and uploaded into a handheld GPS receiver to facilitate field navigation. In the field, each plot was located using the GPS, and the plot center coordinates were re-recorded to verify positional accuracy. Within each plot, all live trees with a diameter at breast height (DBH) ≥ 10 cm were identified and measured. The DBH of trees was measured at 1.3 m above ground level following standard forest inventory procedures using a DBH tape.

Data Analysis

Diameter at breast height (DBH) data were first examined using descriptive statistics and a frequency histogram to assess the general shape, skewness, and variability of the distribution. Several candidate probability distribution models were then fitted to the pooled DBH dataset, as no single distribution is universally suitable for all stand structures. Seven commonly used models, the Weibull, Gamma, Lognormal, Normal, Cauchy, Exponential, and Logistic distributions, were selected and their parameters estimated using maximum likelihood estimation. The functional forms and references for these models are presented in Table 1. The fitting of the statistical distribution models was done at the stand level, where the models were fitted to the pooled sampled data.

Table 1: Diameter Distribution Fitted for the Study Area

Distribution	Equation	Parameter	Reference
Weibull	$f(x) = \left(\frac{c}{b}\right)\left(\frac{x}{b}\right)^{c-1} e^{-(x/b)^c}$	b = scale, c = shape	Bailey & Dell (1973)
Gamma	$f(x) = \frac{1}{\Gamma(a)b^a} e^{-x/b} x^{a-1}$	a = shape, b = scale	Krishnamoorthy (2006)
Lognormal	$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-(lnx-\mu)^2/2\sigma}$	μ = location, σ = scale	Limpert *et al*. (2001)
Normal	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2}$	μ = mean, σ = standard deviation	Krishnamoorthy (2006)
Cauchy	$f(x) = \frac{1}{\pi b[1 + ((x-a)/b)^2]}$	*a* = location, *b* = scale	Krishnamoorthy (2006)
Exponential	$f(x) = \frac{1}{b} e^{-x/b}$	*b* = scale	Krishnamoorthy (2006)
Logistics	$f(x) = \frac{1}{b} \cdot \frac{e^{-(x-a)/b}}{[1 + e^{-(x-a)/b}]^2}$	*a* = location, *b* = scale	Johnson *et al*. (1994)

The distribution models were evaluated using Kolmogorov-Smirnov (KS), Anderson-Darling (AD) and Cramer-von Mises (CVM) goodness of fit and were ranked accordingly. These metrics compare the empirical and theoretical cumulative distribution functions and quantify the degree of agreement between them. Smaller values of these statistics indicate a closer fit and therefore a more suitable model.

3. Results

Summary Statistics of Tree Diameter and Species Composition in the Woodland Area

The summary statistics result (Table 2) describes the characteristics of tree stem diameters, measured at breast height (DBH), within the woodland. The average DBH (10.3 cm) indicates that trees in the area have an average size in structure. The variation in stem diameters, having a standard deviation of 5.4 cm, implies a heterogeneous tree population consisting of individual trees at different stages of growth. The observed minimum and maximum DBH of 4.6 cm and 41.1 cm, respectively, show a wide range of tree sizes, consisting of smaller trees and more mature individuals. The kurtosis of 10 shows a sharply peaked distribution with extended tails, implying that most of the individual trees are clustered around the mean diameter, and a few trees with larger diameters exert a disproportionate influence on the distribution. The skewness value (2.3) points to a right-skewed distribution, indicating a greater frequency of smaller-diameter trees and a few trees with larger diameters. Thus, these statistics (Table 2) show a population dominated by smaller trees, with a few larger individuals contributing to a positively skewed and peaked diameter distribution.

Table 2: Summary statistics of measured growth variables

Descriptive Statistics	Diameter at Breast Height (cm)
Mean	10.3
Standard Deviation	5.4
Kurtosis	10
Skewness	2.3
Minimum	4.6
Maximum	41.1
Sample Size	119

The tree species composition and abundance within the woodland area (Table 3) comprises of thirty (30) tree species distributed across fourteen (14) families with varying density (number of individuals per hectare, N/ha) and relative frequency (R.F.). Based on the fourteen families, Fabaceae (Leguminosae) is the most dominant family with many species. The family contains several taxa, such as *Daniella oliverii*, *Detarium microcarpum*, and *Albizia zygia*, among others. *Daniella oliverii* recorded the highest number of individual trees among all species, with 22 trees counted per hectare. It also showed the highest relative frequency, accounting for 18.5% of the total tree population in the woodland. *Gmelina arborea* contributed 17.6% to the total composition, while *Azadirachta indica*, from the Meliaceae family, had 12.6%. Gmelina arborea had 21 individuals per hectare, while *Azadirachta indica* had 15. Fewer species, such as *Detarium microcarpum* and *Hannoa undulata*, each had a presence of seven trees per hectare. *Lophira lanceolata* was slightly less represented, with six individuals per hectare. *Vitellaria paradoxa*, *Parinari curatellifolia*, *Quassia undulata*, and *Terminalia mentalis* each had a density of two trees per hectare.
Fourteen (14) tree species (*Terminalia avicennioides, Terminalia schimperiana, Trichilia emetica, Ficus sycomorus, Khaya senegalensis, Lannea schimperi, Maranthes polyandra, Parkia biglobosa, Pterocarpus erinaceus, Terminalia djalonensis, Combretum nigricans, Elaeis guineensis, Pterocarpus erinaceus, and Strychnos spinosa*) had lower abundance values, each of which had one tree per hectare. *Daniella oliverii* had the highest relative frequency values of 18.5%, indicating variance in density. The percentages for *Azadirachta indica* and *Gmelina arborea* were 12.6% and 17.6%, respectively. In the mid-range, species such as *Hannoa undulata* and *Detarium microcarpum* contributed 5.9% each, while *Syzygium guineense* contributed 3.4% and *Lophira lanceolata* contributed 5.0%.

Table 3: Tree Species Composition and Abundance in the Woodland Area

S/No.	Species	Family	N/ha	R.F
1	*Albizia zygia*	Fabaceae (Leguminosae)	4	3.4

2	*Anacadium occidentale*	Anacardiaceae	3	2.5
3	*Anthocleista djalonensis*	Loganiaceae	1	0.8
4	*Azadirachta indica*	Meliaceae	15	12.6
5	*Burkea Africana*	Fabaceae	3	2.5
6	*Combretum nigricans*	Combretaceae	1	0.8
7	*Crossopteryx febrifuga*	Rubiaceae	2	1.7
8	*Daniella oliveri*	Fabaceae	22	18.5
9	*Detarium microcarpum*	Fabaceae	7	5.9
10	*Elaeis guineensis*	Arecaceae	1	0.8
11	*Ficus sycomorus*	Moraceae	1	0.8
12	*Gmelina arborea*	Verbenaceae	21	17.6
13	*Hannoa undulate*	Simaroubaceae	7	5.9
14	*Khaya senegalensis*	Meliaceae	1	0.8
15	*Lannea schimperi*	Anacardiaceae	1	0.8
16	*Lophira lanceolata*	Ochnaceae	6	5.0
17	*Mangifera indica*	Anacardiaceae	3	2.5
18	*Maranthes polyandra*	Chrysobalanaceae	1	0.8
19	*Parinari curatellifolia*	Chrysobalanaceae	2	1.7
20	*Parkia biglobosa*	Fabaceae	1	0.8
21	*Pericopsis laxiflora*	Fabaceae	1	0.8
22	*Pterocarpus erinaceus*	Fabaceae	1	0.8
23	*Quassia undulate*	Simaroubaceae	2	1.7
24	*Strychnos spinosa*	Loganiaceae	1	0.8
25	*Syzygium guineenses*	Myrtaceae	4	3.4
26	*Terminalia avicennioides*	Combretaceae	1	0.8
27	*Terminalia mentalis*	Combretaceae	2	1.7
28	*Terminalia schimperiana*	Combretaceae	1	0.8
29	*Trichilia emetic*	Meliaceae	1	0.8
30	*Vitellaria paradoxa*	Sapotaceae	2	1.7

Stand Diameter Distribution Models

The parameter estimates (Table 4) for the different statistical models fitted to the growth data collected within the woodland area show that the shape and the scale parameters were estimated at 2.032 (±0.08) and 11.685 (±0.354), respectively, for the Weibull distribution. These values indicate a moderately skewed distribution commonly used to model tree size structure, particularly in forest stands where recruitment and mortality rates vary with size. The Gamma distribution was defined by a shape parameter of 5.14 (±0.41) and a rate parameter of 0.499 (±0.042). The estimates show that the model is flexible and well-fitted for data with a positive skew, like tree diameter measurements. This flexibility enables the model to effectively represent the underlying patterns and variability in tree diameter measurements.

The scale and location parameters for the Lognormal model had 0.422 (±0.017) and 2.232 (±0.024), respectively. The parameters' values align with the modelling of log-transformed variables with right-skewed distributions, which is common for tree diameters. Normal distribution, often used for symmetrical data, had a standard deviation (scale) of 5.413 (±0.221) and a mean (location) of 10.301 (±0.313); these values closely fit the previous descriptive figures for breast height and diameter.

The Cauchy distribution shows the scale and location parameters at 1.881 (±0.153) and 8.000 (±0.169), respectively. The distribution has heavy tails and is less commonly used in ecological modelling; however, it can describe data with extreme outliers. The Exponential distribution was defined solely by a rate parameter, estimated at 0.097 (±0.006). This model assumes a constant hazard rate and is often used for modelling the time between events or decay processes. The Logistic distribution had a scale parameter of 2.583 (±0.129) and a location parameter of 9.387 (±0.253).

Table 4: Parameter estimates of models developed in this Study Area

Models	Parameter Estimates (Standard error in brackets)			
	Shape	Scale	Location	Rate
Weibull	2.032 (0.08)	11.685 (0.354)	-	-
Gamma	5.14 (0.41)	-	-	0.499 (0.042)
Lognormal	-	0.422 (0.017)	2.232 (0.024)	-
Normal	-	5.413 (0.221)	10.301 (0.313)	-
Cauchy	-	1.881 (0.153)	8 (0.169)	-
Exponential	-	-	-	0.097 (0.006)
Logistics	-	2.583 (0.129)	9.387 (0.253)	-

Table 5 presents the results of goodness-of-fit assessments for various statistical distribution models applied to tree diameter data from the woodland area. The adequacy of each model was evaluated using three non-parametric statistical tests: Kolmogorov–Smirnov, Cramér–von Mises, and Anderson–Darling. Model performance was assessed using test statistics, with smaller values denoting greater concordance between model predictions and observed data. The models were then ranked based on their relative performance.

The lognormal distribution demonstrated the strongest performance across all three goodness-of-fit tests, with respective values of 0.112 for the Kolmogorov–Smirnov test, 0.814 for the Cramér–von Mises test, and 4.866 for the Anderson–Darling test, placing it consistently as the best-fitting model. This result suggests that the lognormal model most accurately represents the underlying distribution of stem diameters in the study area. The gamma distribution was the second-best overall fit with K-S, Cramér–von Mises, and Anderson–Darling values of 0.132, 1.444, and 8.425, respectively. The logistic distribution also performed well, ranking third overall.

The Weibull distribution, though widely used in forest stand modelling, exhibited only a moderate level of alignment with the observed data, ranking fourth across all three goodness-of-fit assessments. In contrast, the normal and Cauchy distributions showed relatively weak performance, while the exponential distribution performed the poorest overall. The exponential model yielded the highest values across the Kolmogorov–Smirnov (0.369), Cramér–von Mises (9.826), and Anderson–Darling (48.905) tests, indicating the least suitability for describing the diameter distribution of trees in the study area.

Table 5: Goodness of fit statistics of fitted statistical distribution models developed in the study area

Models	Kolmogorov-Smirnov		Cramer-von Mises		Anderson-Darling	
	Statistics	Rank	Statistics	Rank	Statistics	Rank
Weibull	0.148	4	2.238	4	13.503	4
Gamma	0.132	2	1.444	3	8.425	2
Lognormal	0.112	1	0.814	1	4.866	1
Normal	0.172	6	3.218	6	18.169	6
Cauchy	0.166	5	2.618	5	17.217	5
Exponential	0.369	7	9.826	7	48.905	7
Logistics	0.142	3	1.381	2	11.266	3

The result shows (Figure 1) the graphical comparison of the fitted distribution models and how well different statistical models capture the distribution of tree diameters within the study area. This visual allows for a direct assessment of how closely each theoretical model aligns with the actual distribution of tree diameters. Models that accurately capture the shape and variability of the observed data provide a more realistic representation of the underlying forest structure.

In Figure 2, the histograms are overlaid with the theoretical density curves of each fitted distribution. The histogram illustrates the observed frequency distribution of tree diameters across various size classes, whereas the superimposed curves represent the expected frequency distributions predicted by the mathematical models. A close alignment between the histogram bars and theoretical curves indicates a strong fit. This comparison shows the extent to which a model accurately captures the central tendency and the variability of tree diameter distributions. The empirical cumulative distribution function (CDF) is plotted against the fitted CDFs from the selected models (Figure 3). The empirical CDF is constructed from the observed DBH and serves as a benchmark. When a model is well-fitted, its cumulative curve follows the empirical line across the entire range of diameters. This figure is useful when assessing how well models perform at the lower and upper ends of the diameter range.

Figure 4 presents a probability-probability (P–P) plot, in which the fitted distribution probabilities are plotted against the corresponding empirical probabilities. An ideal model fit is indicated by points aligning closely along the 45-degree reference line. Departures from this line indicate potential overestimation or underestimation of probabilities by the model in specific diameter classes.

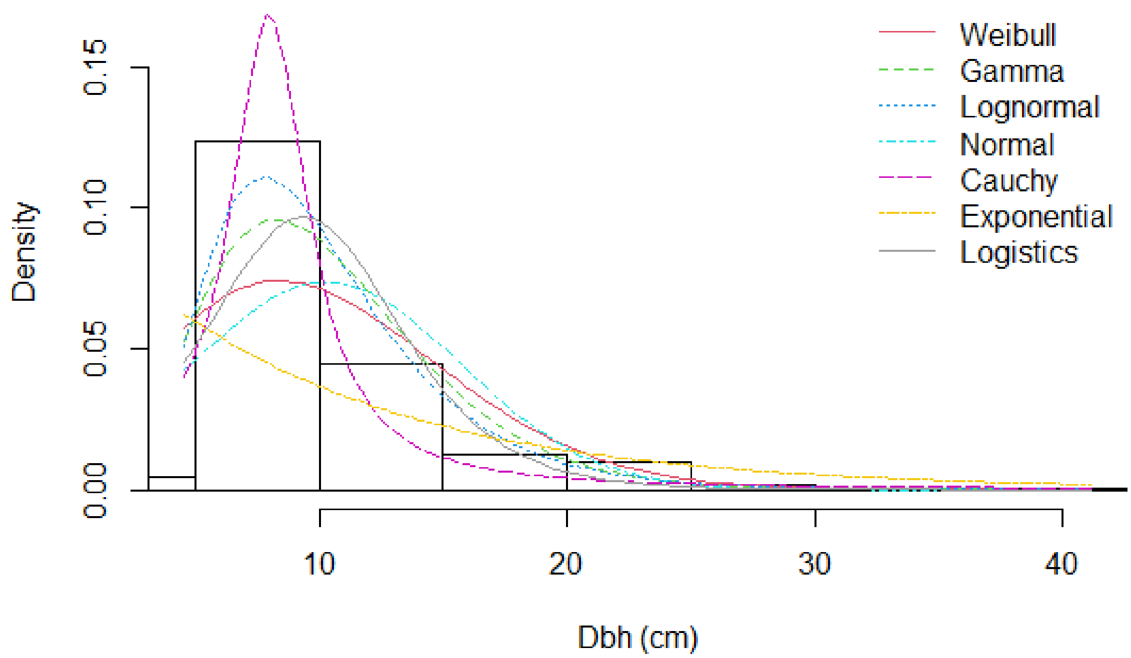

Figure 1: Graphical comparison of the fitted distribution model

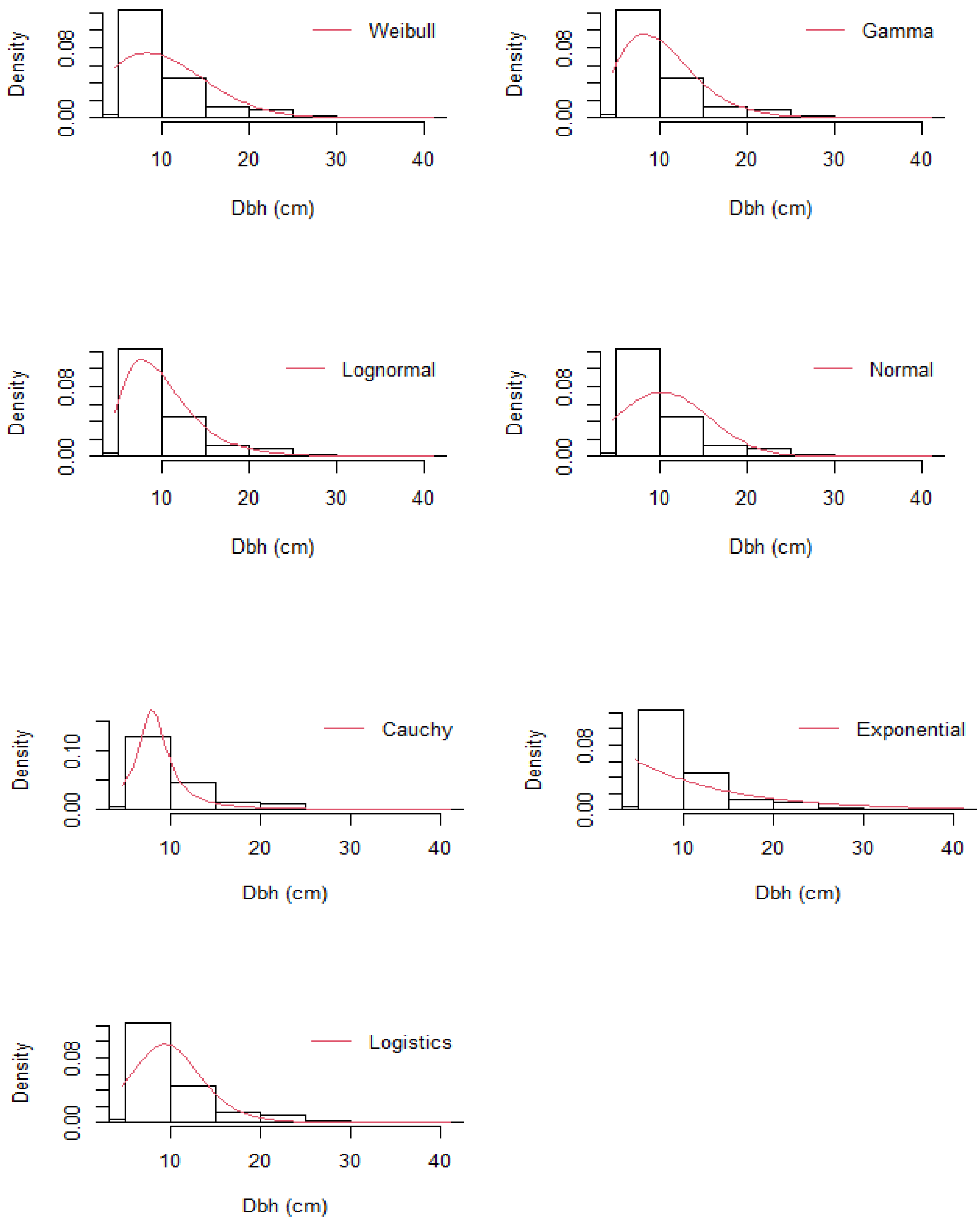

Figure 2: Histogram and theoretical densities of the fitted distribution models

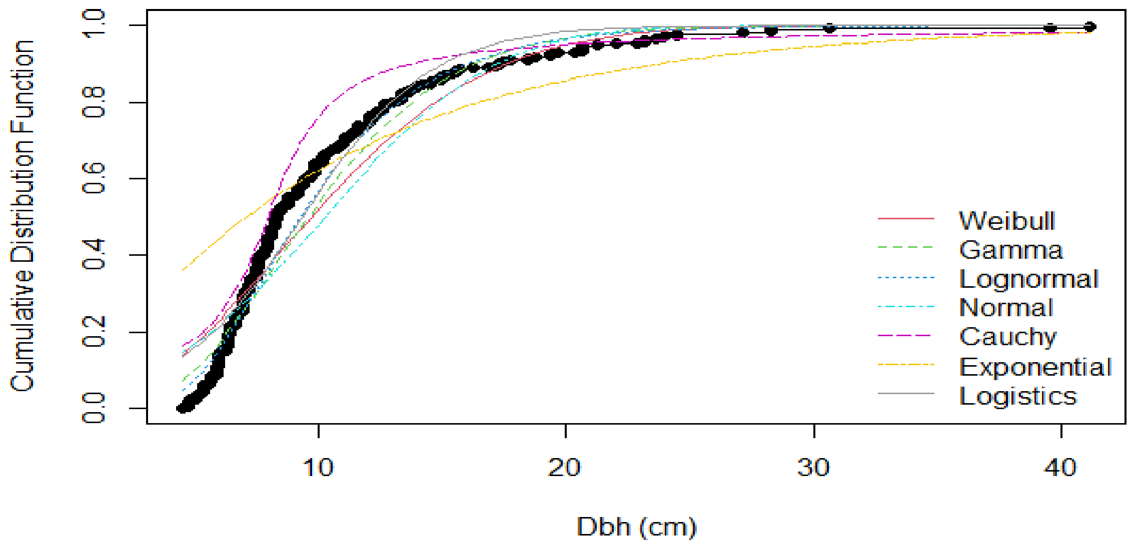

Figure 3: Plot of the empirical cumulative distribution against the fitted distribution functions.

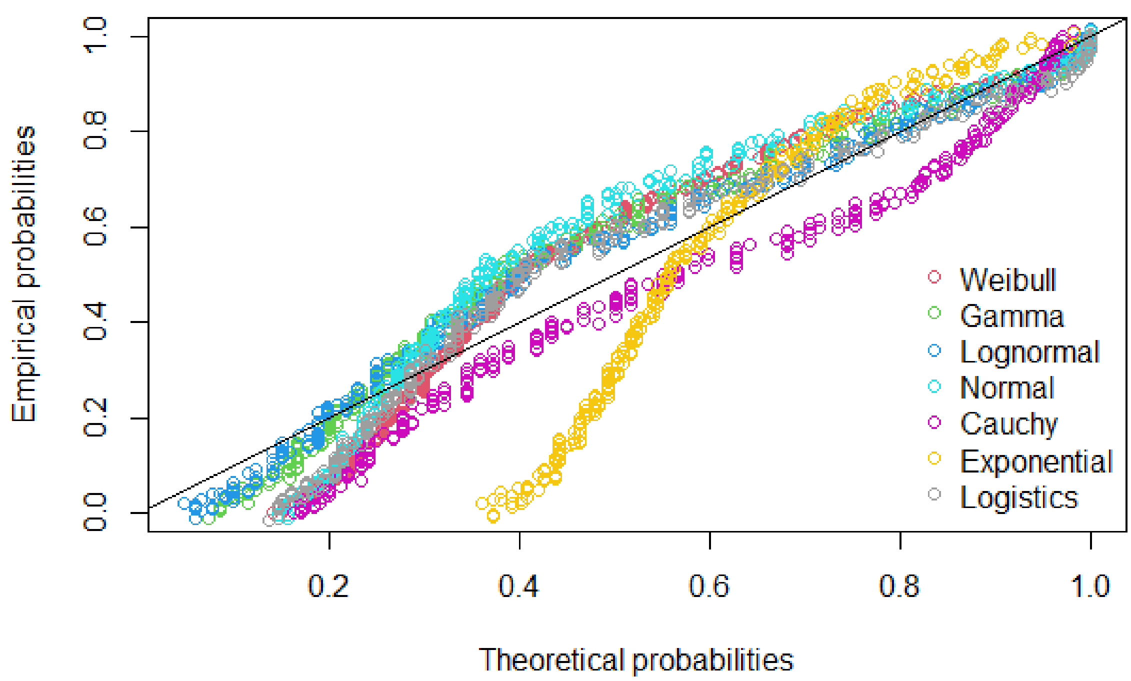

Figure 4: Plot of the probabilities of each fitted distribution against the empirical probabilities

4. Discussions

Summary Statistics of Tree Diameter and Species Composition in the Woodland Area

The study area has a species composition of thirty (30) tree species belonging to 14 families, with Fabaceae as the dominant family. Adaptation to woodland habitat is exhibited by the dominance of Fabaceae species (e.g., *Daniella oliverii or Detarium microcarpum or Albizia zygia*). This trend is consistent with the results of the Nigerian trees, where the family Fabaceae was frequently dominant (Salami and Lawal, 2018; Amonum *et al.,* 2019; Chenge *et al.,* 2019; Seyni *et al.,* 2021; Onyekwelu *et al.,* 2022; Japheth and Meer, 2023). Each species at the species level had its highest relative frequency and density (22 individuals/ha -1), indicating its competitive edge and possible regeneration process. There were also other species (*Gmelina arborea, Azadirachta indica*) of considerable importance; they demonstrated a combination of native and non-native taxa, adapted to the local conditions of the soil and climate. The tree species with economic value to human beings have been exploited, and the depreciation of number of tree species in the woodland. This statement was justified by Komolafe *et al.* (2017), who reported that the use of tree species depends on the economic value of these species.

Diameter Distribution Modelling and Growth

Distribution modelling of diameter is a management tool that is critical in sustainable forest management as it gives information on the structure, regeneration, and yield potential of a forest stand with respect to tree diameter. A heterogeneous structure was observed in the study area of the analysis of the diameter of trees at breast height (DBH). A mean DBH of 10.3cm with a standard deviation of 5.4cm suggests that the woodland has trees with different growth stages, including both low-diameter and mature trees. Positive skewness (skewness = 2.3) and leptokurtic (kurtosis = 10) distributions are characteristics of a forest, with individual trees with smaller diameter sizes being predominant, which is characteristic of a regenerating forest in the tropical setting where a high rate of recruitment and low rate of death or harvesting pressure occur (Forestter, 2019). The result of positive skewness and kurtosis is consistent with the past research (Podlaski and Roesch, 2014; Robson *et al.,* 2016; Ekpa *et al.,* 2020; Adedoyin *et al*., 2021; and Oladoye *et al*., 2024).

The availability of a small number of bigger trees points to the retention of mature individuals, which are relevant to the biomass and carbon storage. The diameter of the tree has a substantial effect on productivity and is commonly used to characterize the structure of the stand (Weiskittel *et al.,* 2011). The results on the trees with lower diameters is in line with the research by Bobo *et al.* (2006), Aigbe and Omokhua (2014) and Oladoye *et al.* (2024), who found similar results in Southwestern Cameroon and Forest reserves in Nigeria, respectively.

The analysis of statistical distributions of DBH data gave information on the structural characteristics of the woodland. It is not just a mathematical puzzle to know the distribution of the diameter of the trees in a forest. It is an impressive method of explaining the condition, composition, and future of a forest. The moderate skewness structure was reflected effectively by the Lognormal distribution (scale 0.422, location 2.232), which was not consistent with the few studies in the natural forest of Nigeria that utilized Weibull models (Ogana and Gorgoso-Varela, 2015). Other suitable representations of the right-skewed DBH data were the Gamma and Logistic distributions; however, the lognormal model had the best overall goodness of fit (Kolmogorov-Smirnov, Cramer von Mises, Anderson-Darling test). According to Lima *et al*. (2017) and Oladoye *et al*. (2024), the Burr distribution function was found to be highly flexible to characterize the diameter structure at the stand in both the Brazilian tropical dry forest and Omo Biosphere Reserve, Ogun State, Nigeria, respectively. Ige *et al*. (2013) described the beta distribution of trees of tropical natural forests in Onigambari Forest Reserve, Southwest Nigeria. Other distributions that were not ideal included exponential, normal, and Cauchy distributions, as they could not explain the high skew and heavy right tail of the data of tree diameters. This result is consistent with the report by Ezenwenyi *et al*. (2018), who mentioned that the 3-parameter lognormal distribution provided a better account of the stem diameter in the limited tropical rainforest in Nigeria.

The strength of the chosen models was also supported with the help of graphical analyses (overlaid histograms, empirical cumulative distribution functions (CDFs), and P–P plots). The proximity between the empirical data and the fitted curve of lognormal and gamma distributions shows that both models can describe the central tendencies as well as the variation in the data of the tree diameter. The observed and predicted DBH classes had no significant difference ($P > 0.05$), meaning that there was a close match between the predicted and the observed distribution. This is in line with the conclusion reached by Adedoyin and Adeoti (2021), Egonmwan and Ogana (2020), and Oladoye *et al.* (2024).

As is also demonstrated in Figures 1 and 2, the typical feature of the curves with long tails, the intermediate diameter classes and the peak in the small diameter classes, implies a structure of modes which is not vague. This kind of distributional behaviour is characteristic of tropical forests and is an indication of the dynamics behind the forest. To manage forests effectively, accurately modelling such distributions is necessary, as it would be used to predict stand structure, estimate volume yield, and develop sustainable harvesting plans.

5. Conclusion

The study area has a species composition of thirty (30) tree species belonging to 14 families, with Fabaceae as the dominant family. The Fabaceae family is the most represented, and *Daniella oliverii* is the most abundant species (22 trees/ha; 18.5% relative frequency). Tree diameter analysis showed a mean DBH of 10.3 cm, with a wide size range (4.6–41.1 cm) and a positively skewed, peaked distribution (skewness = 2.3, kurtosis = 10.0), indicating a population dominated by smaller trees with fewer large individuals. Among the tested statistical models, the Lognormal distribution was adjudged as the best fit to the observed diameter data, followed by the Gamma and Logistic models. The woodland is taxonomically diverse and structurally heterogeneous, indicating a balanced tree community with implications for biodiversity conservation and sustainable woodland management.

References

Adedoyin, E.D, Adeoti, O.O, Awosusi, B.M., Onilude Q and Aina-Oduntan, O. A. (2021). Evaluating the diameter distribution model of Parkia biglobosa Plantation (Jacq.) G.Don in Wasangare, Saki West Local Government Area of Oyo State, Nigeria. Journal of Forestry Research and Management, 18(3).198-206.

Adekunle, V.A.J., Olagoke, A.O., & Akindele, S.O. (2013). Tree species diversity and structure of a Nigerian tropical rainforest ecosystem. International Journal of Biodiversity Science, Ecosystem Services & Management, 9(3), 248–259.

Aigbe H. I and Omokhua G.E. (2014). Modelling Diameter Distribution of the Tropical Forest in Oban Forest Reserve. Journal of Environment and Ecology 5 (2):130-143.

Akpen, G.D.; Aho, M.I. and Adejo, M. G. (2019): Aquifer Characteristics of Some Local Government Areas Of Benue State, Nigeria; *Nigerian Journal of Technology (NIJOTECH);* 38 (1): 233 – 241.

Amonum, J. I., & Japheth, H. D. (2019). Application of developed crown-bole diameter model to stand density and stock control on open-grown trees of *Prosopis africana* (Guill and Perr) Taub. *Journal of Applied Tropical Agriculture, 24*(2), 32–39.

Amonum, J.I., Dau J. H. and Gbande, S. (2016). Composition And Distribution of Economic Tree Species In Nagi Forest Reserve, Benue State, Nigeria. *Journal of Research in Forestry, Wildlife and Environment,* 8(4), 101-108.

Amonum, J.I., Jonathan, B.A., Japheth, H.D (2019). Structure and Diversity of Tree Species at the College of Forestry and Fisheries, University of Agriculture Makurdi, Benue State, Nigeria. *International Journal of Forestry and Horticulture* (IJFH), 5 (1): 20-27. DOI: 10.13140/RG.2.2.36807.75686

Anderson, T.W. and Darling, D.A. (1954). A Test of Goodness of Fit. Journal of American Statistical Association, 49, 765-769. https://doi.org/10.1080/01621459.1954.10501232

Arshad M, Rasool MT, Ahmad MI (2003): Anderson Darling and modified Anderson Darling tests for generalized Pareto distribution. Pak J Appl Sci 3(2):85–88

Avery, T. E., & Burkhart, H. E. (2002). *Forest measurements* (5th ed.). McGraw-Hill.

Bailey, R.L., & Dell, T.R. (1973). Quantifying diameter distributions with the Weibull function. Forest Science, 19(2), 97–104.

Binoti D.H.B., Binoti M.L.M.S., Leite H.G., Garcia S.L.R and Cruz J.P. (2011). Modelos de distribuição diamétrica para povoamentos desbastados de eucalipto utilizando a função hiperbólica. *Árvore.* 35(5): 1069-1076. http://dx.doi.org/10.1590/ S0100-67622011000600013.

Bobo, K.S., Waltert, M., Njokagbor, J., Fermon, H.,& Muhlenbeg,M. (2006). From forest to farmland: Species richness patterns of tree and understorey plants along a gradient of forest conversion in Southwestern Cameroon. Biodiversity and Conservation, 15, 4097-4117.

Chenge, I. B., Chukwu, O., Japheth, H. D., & Yager, G. O. (2019). Tree species diversity and forest structure of a natural forest in Shasha Natural Forest, Nigeria. Forestry Association of Nigeria, Abuja.

Conover, W.J. (1999): Practical Nonparametric Statistical. 3rd Edition, John Wiley & Sons Inc., New York, 428-433.

Dau, J. H., & Chenge, I. (2016). Growth space requirements models for *Prosopis africana* (Guill and Perr) Taub tree species in Makurdi, Nigeria. *European Journal of Biological Research, 6*(3), 209–217.

DeLiocourt F (1898). De lamenagement des Sapiniers. Bul Social ForestFranche-Comptéet Belfort, pp. 396-409.

Egonmwan I. Y and Ogana F. N (2020). Application of diameter distribution model for volume estimation in Tectona grandis L.f. stands in the Oluwa forest reserve, Nigeria. Tropical Plant Research 7(3): 573–580.

E-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/, April, 2012.

Ekpa, N. E., Daniel, K.S., Ukpong, E.E, Etigale, E.B., & Asuquo. O.E. (2020). Modeling Tree Diameter

Distributions in Arboretum of Forestry and Wildlife University of Uyo: An Evaluation of 8 Statistical Models. Global Journal of Science Frontier Research, 20 (H2), 13–18.

Ezenwenyi, J.U., Oladoye, A.O., Chukwu, O. and Basiru, A.O. (2018). Diameter distribution of Nauclea diderrichii (D Wild) Merr. Plantations in a restricted Tropical Rainforest in Nigeria. Journal of Research in Forestry, Wildlife & Environment, 10 (3):25–32.

Forrester, D. I. (2019). Linking forest growth with stand structure: Tree size inequality, tree growth or resource partitioning and the asymmetry of competition. Forest Ecology and Management, 447, 139-157. https://doi.org/10.1016/j.foreco.2019.05.053

Gorgoso J.J., Álvarez-González J.G., Rojo A., Grandas-arias J.A., (2007). Modelling diameter distributions of *Betula alba* L. stands in northwest Spain with the two parameter Weibull function. *Invest. Agrar.: Sist. Recur. For.* 16(2): 113-123.

Gorgoso-Varela, J. J., A. Rojo-Alboreca, E. Afif-Khouri and M. Barrio-Anta (2008). Modelling diameter distributions of birch (*Betula alba* L.) and Pedunculate oak (*Quercus robur* L.) stands in northwest Spain with the beta distribution. Investigación Agraria: *Sistemas y Recursos Forestales* 2008 17(3), 271-281

Güner, Ş. T., Diamantopoulou, M. J., & Özçelik, R. (2023). Diameter distributions in Pinus sylvestris L. stands: Evaluating modelling approaches including a machine learning technique. Journal of Forestry Research, 34(6), 1829–1842. https://doi.org/10.1007/s11676-023-01625-2

Husch, B., Beers, T.W., & Kershaw, J.A. (2003). Forest Mensuration (4th ed.). Wiley.

Ige, P. O., Akinyemi, G. O., & Abi, E. A. (2014). Diameter distribution models for tropical natural forest trees in Onigambari Forest Reserve. *Journal of Natural Sciences Research*, 3 (12), 14.

Japheth H.D and Meer, B.B (2023): Structure, Alpha and Beta Diversity of Natural Forest Areas in Three Eco-Zones of Taraba State, Nigeria; *Journal of Forestry and Environmental Service. Journal of Forest and Environmental Science*, 39 (1): 1-12.

Kolmogorov, A. (1933): Sulla determinazione empirica di una legge di distribuzionc, *1st. Ital. Attuari*. G.. **4**. 1–11.

Komolafe AA, Adegboyega SA, Akinluyi FO (2017). A review of flood risk analysis in Nigeria. American Journal of Environmental Sciences pp. 157-166.

Leak W.A., (1996). Long-term structural change in unevenaged northern hardwoods. *For. Sci*. 42: 160-165.

Lima, R. B, Bufalino, L, Alves Junior, F. T, Silva, J.A. D, Ferreira, R. L (2017). Diameter distribution in a Brazilian tropical dry forest domain: predictions for the stand and species. Anais da Academia Brasileira de Ciências; 89(2):1189-1203.

Liu C., Zhang S.Y., Lei Y., Newton P.F., Zhang L., (2004). Evaluation of three methods for predicting diameter distributions of black spruce (*Picea mariana*) plantations in central Canada, *Can. J. For. Res*. 34: 2424-2432.

Longman, K. A. and Jenik, K. (2000). *Tropical Forest and its Environment*. Longman 12th Edition, U.K. 147pp.

Lorimer C.G., (1980). Age Structure and Disturbance History of a Southern Appalachian Virgin Forest. *Ecology, 61*: 1169-1184.

Lykke, A.M., & Svensson, J.S. (2002). Structure, biomass, and species diversity of dry woodlands in Burkina Faso.Journal of Tropical Ecology, 18, 565–585.

Maltamo, M. and A. Kangas. (2008). Methods based on k-nearest neighbour regression in the estimation of basal area diameter distribution. Canadian Journal of Forest Resources. 28:1107-1115.

Mbah, A.O., & Umunna, M.O. (2015). Assessment of diameter distribution models in a tropical secondary forest. Journal of Tropical Forest Science, 27(2), 236–245.

Nelson T.C. (1964). Diameter distribution and growth of loblolly pine. Forest Sci., 10: 105-115.

Nornadiah Mohd Razali and Yap Bee Wah (2011): Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling tests; *Journal of Statistical Modeling and Analytics; 2(1): 21-33.*

Ogana FN & Ekpa NE (2020) Modelling the non-spatial structure of Gmelina arborea Roxb Stands in the Oluwa Forest Reserve, Nigeria. Forestist 70 (2): 133–140.

Ogana, F.N., & Itam, E.S. (2016). Diameter distribution modelling of tropical rainforest trees using probability density functions. Journal of Forestry Research, 27(4), 799–808.

Ogana, Friday & Gorgoso-Varela, J.. (2015). Comparison of estimation methods for fitting Weibull distribution to the natural stand of Oluwa Forest Reserve, Ondo State, Nigeria. Journal of Research in Forestry, Wildlife and Environment. 7. 81.

Oladoye, A. O., Akindele, S. O., & Adekunle, V. A. J. (2024). Development of diameter distribution models for the management of Omo Biosphere Reserve, Ogun State, Nigeria. *Applied Tropical Agriculture*, 29 (2), 8–17.

Onyekwelu, J., Agbelade, A., Tolorunju, M., Lawal, A., Stimm, B., and Mosandl, R. (2022): Conservation potentials, tree species diversity, distribution, and structure of sacred groves in southwestern Nigeria. *Journal of Tropical Forest Science*, *34*(3), 334–346.

Piqué-Nicolau M, Del Río M, Calama R. and Montero G. (2011). Modelling siviculture alternatives for managing *Pinus pinea* L. Forest in North-East Spain. *Forest Systems.* .20(1): 3-20. http://dx.doi.org/10.5424/fs/2011201-8464.

Podlaski R, and Roesch FA (2014) Modelling diameter distributions of two-cohort forest stands with various proportions of dominant species: a two-component mixture model approach. Math Biosci 249:60 74.

Poudel KP & Cao QV (2013). Evaluation of methods to predict Weibull parameters for characterising diameter distributions. *Forest Science* 59(2): 243–252.

Richards, P. W. (2006). The Tropical Rainforest: An Ecological Study. University of Cambridge Press, Cambridge. 575pp.

Robson, B.L, lima, B, Francisco, T, Jose, A, Rinaldo, L (2016). Diameter distribution in a Brazilian tropical dry forest domain: predictions for the stand and species. Anais da Academia Brasileira de Ciências 89(2):1189-1203

Salami KD, Lawal AA (2018). Description of economic tree and shrub species in the Northern part of Nigeria and their potentials. Proceedings of the 6th Biennial National Conference of the Forests and Forest Products Society pp. 136-144.

Seyni, B. M., Awodoyin, R. O., Olubode, O. S., Adeniji, S. A., & Ibrahima, D. B. (2021). Floristic composition, diversity and community structure in a secondary rainforest in Ibadan, Nigeria. International Journal of Biodiversity and Conservation, 13(4), 183-199. doi: 10.5897/IJBC2020.1463

Tsogt, K., Zandraabal, T. and Lin, C. (2013). Diameter and height distributions of natural even–aged Pine forests (Pinus sylvestris) in Western Khentey, Mongolia. Taiwan Journal of Forest Science 28(1):29– 41.

Turner, I. M. (2001). The ecology of trees in the tropical rain forest. Cambridge University Press, Cambridge, UK. 298pp.

Whitmore, T. C. (1998). *An introduction to tropical rainforests. Second Edition*. Oxford University Press, Oxford. 296p.

10/21/2025