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Evaluating diameter distribution model of *Parkia biglobosa* Plantation (Jacq.) G.Don in Wasangare, Saki West Local Government Area of Oyo State, Nigeria

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ABSTRACT

Diameter at breast height (dbh) is the most important forest stand variable during inventory owing to its relation to other important stand variables and relative ease with which its measurements are assessed. This study therefore evaluated the probability distribution function characterizing the diameter measurements of even-aged *Parkia biglobosa* stands in Wasangare, Oyo State, Nigeria. A total of 35 sample plots of size $20m \times 20m$ were located within the study site using stratified random sampling method. Exploratory analysis of the collected observations using histogram showed that the observation was right–skewed consequently resulting in the consideration of six commonly used probability distributions(Lognormal, Gamma, Weibull, Exponential, Rayleigh and Johnson's S_B) with positive support. Parameters of each distribution was estimated using the method of maximum likelihood. Gamma and Johnson's S_B distributions had the least Akaike Information criterion (AIC) (i.e. 8377.386 and 8378.897, respectively) and Bayesian Information criterion (BIC) values (i.e. 8387.556 and 8399.237, respectively), which were not statistically significantly different at 95% confidence interval, among the distributions. A Kolmogorov-Smirnov and Anderson-Darling goodness of fit tests affirmed the results of the AIC and BIC values. Hence, the Gamma and Johnson's S_B distributions were adjudged the most flexible (or most fit)of the distributions.

Keywords: Dbh, *Parkia biglobosa*, Diameter distribution models, Parameter Estimation.

Introduction

Diameter at breast height (dbh) measurement is the most important stand variable assessed during forest inventory. This is because of the ease with which it is acquired on the field and the relationship it has with other important tree variables which are relatively more difficult to assess; the ease of acquisition reduces the risk of measurement error while the relation it has with other variables allow estimating the more difficult–to–assess (e.g. height, crown diameter, age, density, composition etc.) variable(s) from the relatively easier–to–assess variable (Shamaki *et al*., 2019). dbh is a measure of the trunk of a tree at the height of an adult's breast, taken at approximately 1.30m (4.30ft) above ground level around a tree's trunk using specialized instruments, while the underlying distribution characterizing these measurements is referred to as diameter distribution.

The relationship between dbh and other variables have been exploited by several authors at different times and at different locations. For instance, dbh are used together with height measurements for stand height prediction models(Koirala *et al*., 2017; Ige *et al*., 2019), with crown dimension measurements for crown width estimation models (Akiyemi *et al*., 2012; Ogana, 2019; Onilude *et al*., 2015) and crown projection area prediction(Shimano, 1997) and form a major variable in building volume estimation models (Koirala *et al*., 2017).Diameter measurements could also be used as a base variable in the description of a forest's structure, product mix, product value and forest operational costs as well as in size distribution models(e.g. in diameter distribution models) (Nord–Larsen and Cao, 2006; Ogana *et al*., 2016; Aigbe and Omokhua, 2014).

The development of a diameter distribution model revolves around identification of the family of probability distribution for a choice variable, determination of the most probable distribution from the family of distribution and estimationof the parameter(s) of the selected mode l(Langat *et al*., 2019; Ogana *et al*., 2016). Though this process is time demanding, it still remains an active area of researchowingof its simplicity and effectiveness in describing the characteristics of a given stand (Shamaki *et al*., 2019, Nord–Larsen and Cao, 2006).Some probability distributions that have been used for describing forest stand structure include: beta distribution (Gorgoso–Varela *et al*., 2008; Ige *et al*., 2013), gamma distribution (Mirzaei *et al*., 2015), Burr distribution (Tsogt *et al*., 2013), Johnson's S_B distribution (Hafley and Schreuder, 1977; Rennolls and Wang, 2005; Knoebel and Burkhart, 1991; Scolforo *et al*., 2003;Tsogt *et al*., 2013) and Weibull distribution (Bailey and Dell, 1973; Nord–Larsen and Cao, 2006; Rennolls *et al*., 1985; Gorgoso *et al*., 2012; Ezenwenyi *et al*., 2018). Despite the wide application of probability distribution methods for modelling several different tree species, little, or no literatures exist, on the development of diameter distribution models for the management of *Parkia biglobosa*, particularly at the study area. Therefore, the aim of this study was to determine the most flexible probability distribution model for *Parkia biglobosa* tree species to aid in the management of the species.

Parkia biglobosa (Jacq. Benth), popularly known as African locust bean, is a perennial multipurpose woody forest legume tree of the Fabaceae family (Builders *et al.*, 2012; Kalinganire *et al.*, 2007). It is one of the choice trees for agroforestry farmers in semiarid and sub–tropical parts of West Africa(Builders, 2014) notably because of its many valuable non–wood products and its soil fertility improvement capacity (Kalinganire *et al*., 2007).In Nigeria, a large volume of documentation exist on the use of the tree's extracts (sourced from the leaves, roots and stem barks) for treatment of sicknesses (for example, malaria, diabetes mellitus and pains and so on.) and diseases (such as diarrhea and inflammatory ailments) (Builders *et al*., 2012) and as anti–snake venoms (Builders, 2014). The tree's seeds are used as spices, or condiment, in foods and soups across the shores of Nigeria and parts of West Africa (Ige *et al*., 2019; Kalinganire *et al*., 2007) while the stems and roots are used for making pestles, mortars, hoe handles, seats and sometimes used for lighting (in the case of firewood and charcoal) in rural communities.

Materials and Methods

Study Area

This study was carried out on a ten hectare *Parkia biglobosa* plantation in Wasangare, Saki West Local Government Area of Oyo State in Nigeria. The site lies within latitude 8.8558°N and 8.8573°N and Longitude 3.42353°E and 3.42519°E (Figure 1).The plantation was established in 1995by the World Bank to study the growth pattern of the provenances of *Parkia biglobosa* and consequently handed over, for supervision and management, to Forestry Research Institute of Nigeria (FRIN).The study area has its highest temperature occurring around March, at approximately 28.1°C, while its lowest temperature occurs between June and July, at approximately 24.5°C. The area also has a yearly rainfall average of about 1,500mm with a peak occurring in September (Ige *et al*., 2019).

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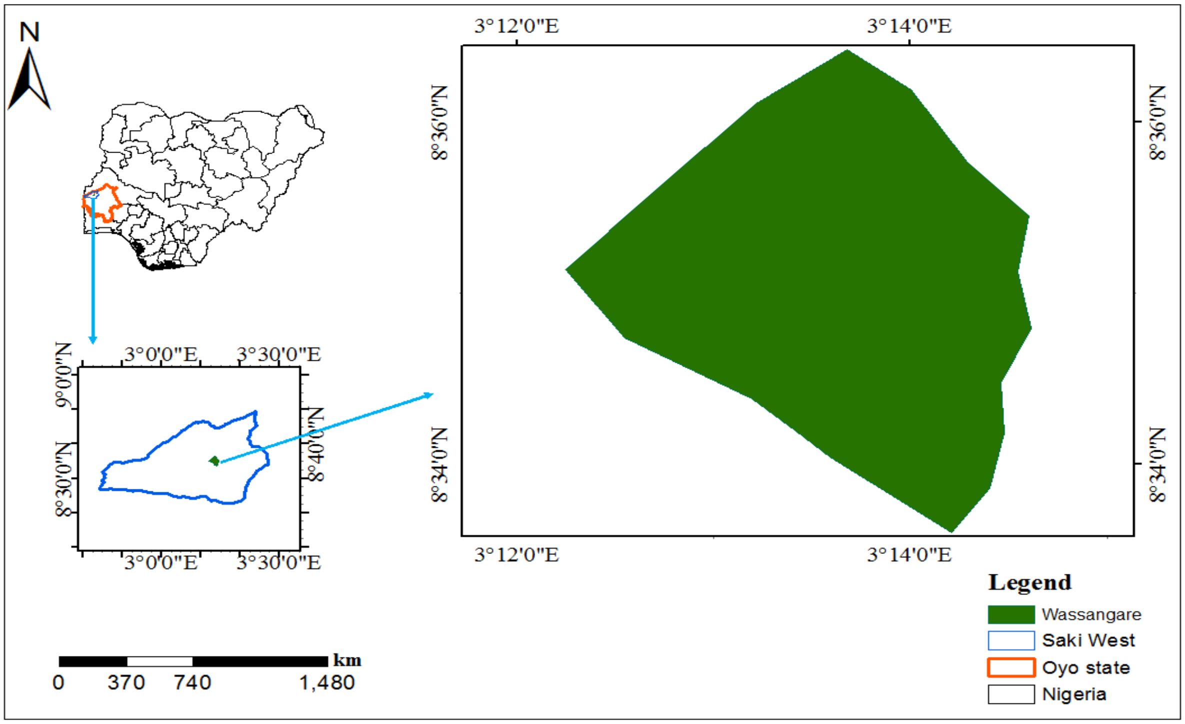

Figure 1: Study Area (**Source: Remote Sensing and GIS section, FRIN**)

Data Collection

Diameter measurements used for this study were obtained from a total of 35 sample plots of $20m \times 20m$laidusing stratified random sampling method within the study site. The dbh, diameter over back at the base were measured using a diameter/girth tape, diameters at middle and at top were measured using Spiegel Relaskop while the height of each stand was measured using a range finder. Each tree's crown diameter was obtained as an arithmetic mean of two perpendicularly measured crown widths measured using a metre rule in the north-south and east-west directions. A summary statistics of the measured variables is presented on Table 1. The analysis of the dataset was done using R statistical software, version 4.0.3.

Table 1: Summary of measured variables

Stand variable	Mean	Standard deviation	Range	Skewness	Kurtosis
dbh (cm)	18.66	8.64	2.00 – 61.70	1.16	1.44
Height (m)	8.15	3.45	1.80 – 21.00	0.71	0.07
Crown diameter (m)	5.90	2.67	1.00 – 28.00	1.44	5.32
CPA (m^2)	32.95	35.29	0.79 – 615.83	–	–
Basal area (m^2)	0.03	0.03	0.0003 – 0.2990	–	–
SLC	50.04	29.50	10.61 – 354.17	–	–

dbh = Diameter at breast height; CPA = Crown Projection Area; SLC = slenderness coefficient

Data Analysis

A crude, but effective, form for investigating the probable probability density function (pdf) of a random variable is to use a histogram. Going by Hogg *et al.* (2019) assertion, let $x_1, \ldots, x_n$ be measurements on the dbh with unknown probability density function (p.d.f) $f(x)$. Also, let there be a positive integer m, a bandwidth $h > 0$ and a value b such that $b < min(x_i)$ so that there are m intervals on $A_j = (b + (2j-3)h,\ b + (2j-1)h]$ for $j = 1, \ldots, m$ which covers the range of the sample $[min(x_i), max(x_i)]$. Then $\hat{f}_h(x)$, then the histogram estimate may be defined as $\hat{f}_h(x) = \frac{\#\{x_i \in A_j\}}{2hn}$.

Model Selection

Six different continuous distribution models (Table 2) commonly used for characterizing biological processes were considered on the basis of the histogram plot (Figure 2) of the dbh observations and the dbh's skewness and kurtosis values (Table 1).

Table 2: Description of the probability distribution models

Index	Distribution	Model description
M1	Lognormal	Form: $f(x) = \frac{1}{\sqrt{2\pi}}\frac{\sigma^{-1}}{x}\exp[-\frac{\sigma^{-2}}{2}(\log x - \mu)^2$ Parameter: $\mu \epsilon (-\infty, +\infty), \sigma > 0$
M2	Gamma	Form: $f(x) = \frac{\beta^\alpha}{\Gamma(\alpha)} x^{\alpha-1}\exp(-\beta x)$ Parameter: $\alpha > 0, \beta > 0$
M3	Weibull	Form: $f(x) = \frac{\alpha}{\sigma}\left(\frac{x}{\sigma}\right)^{\alpha-1}\exp\left[-\left(\frac{x}{\sigma}\right)^{\alpha}\right]$ Parameter: $\alpha > 0, \sigma > 0$
M4	Exponential	Form: $f(x) = \lambda \exp(-\lambda x)$ Parameter: $\lambda > 0$
M5	Rayleigh	Form: $f(x) = x\,\sigma^{-2}\exp\left[-\frac{1}{2}(x\,\sigma^{-1})^2\right]$ Parameter: $\sigma > 0$
M6	Johnson S_B	Form: $f(x) = \left(\frac{\delta}{\sqrt{2\pi}}\right)\left[\frac{\lambda}{(\xi+\lambda-x)(x-\xi)}\right]\exp\left\{-\frac{1}{2}\left[\gamma + \delta\, In\left(\frac{x-\xi}{\xi+\lambda-x}\right)\right]^2\right\}$ Parameter: $\xi \epsilon (-\infty, +\infty), \gamma \epsilon (-\infty, +\infty), \lambda > 0, \delta > 0$

$x$in each model rep.dbh; M(i) connote Model with indexing parameter i such that i = 1, …,6

Model Estimation and Validation

The parameters of the candidate probability distribution models (Table 1) were estimated using the method of maximum likelihood of estimation. Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) were used to determine the best fit probability density function amongst the six candidate density functions. Kolmogorov–Smirnov's (K–S) goodness of fit test and Anderson–Darling's (A–D) goodness of fit test, on the other hand, served as confirmatory tests for appropriateness of the result produced by the AIC and BIC.

Results and Discussion

A summary of the measured variables is presented on Table 1.The values measured on the dbh varied between 2.00cm and 61.70cm. The mean of these dbh measurements was 18.66cm. This mean value, compared with the range, showeda departure from centrality in the dataset which was confirmed by the skewness of the dbh values. The skewness of the dbh measurement was 1.16 connoting a positive skew. A positively skewed observation are such with most observations concentrated at the lower distribution class (Aigbe and Omokhua, 2014). For dbh dataset, larger number of trees were observed at the lower distribution class (Figure 2). This observed pattern was because the plantation comprised different accessions of *Parkia biglobosa* stands, consequently showing different diameter growth rate. The assessed trees had an average height of 8.50m and mean crown diameter of 5.90m and each was observed to be positively skewed, having skewness of 0.71 and 1.44, respectively. The estimated crown projection area was observed to vary between0.79m^2 and 615.83m^2,estimated basal area varied between 0.0003m^2 and 0.2990m^2 while the estimated measure of the trees' slenderness coefficient varied between 10.61 and 354.17. A summary of the estimated models is presented on Table 3.

The Gamma distribution was observed to have the smallest AIC (8377.386)and BIC (8387.556) values out of the six estimated models. This values were observed to be closely followed by the AIC (8378.897) and BIC (8399.237) values of Johnson SB's distribution while exponential distribution had the highest AIC (9379.686) and BIC (9384.771) values. Since lower AIC value connotes better fit than a larger AIC value, the Gamma distribution could be adjudged the best fitting distribution amongst the six. Further test of the fit of the distributions using Kolmogorov-Smirnov (KS)and Anderson-Darling (AD) goodness of fit tests (Table 3) produced statistically significant result at 5% confidence interval for the Lognormal, Weibull, Exponential and the Rayleigh distributions. This means that these four distributions (Lognormal, Weibull, Exponential and Rayleigh) poorly fitted the dbh dataset. The Gamma and Johnson SB distributions were however observed to produce a nonsignificant result. Since the decision rule for the KS test is that a higher KS value means better result than a contemporary lower value, the Johnson SB probability distribution is chosen as a better fit model than the Gamma distribution. The KS test is a nonparametric test and it produces more reliable result than the AIC result, particularly when testing the fit of distributions with varied number of parameters. A plot of the fitted distributions is presented on Figure 3.

Unlike the findings of Ogana and Dau (2019) which derived the crown distribution of *Parkia biglobosa* stands from a dbh measurement values affirmed to follow the Weibull and Log-logistic probability distribution models, this study investigated the underlying dbh growth pattern of an even-aged *Parkia biglobosa* comprising different provenances. As observed by Sedighi *et al.* (2021), the two-parameter gamma distribution model provided consistent approximation for this dataset owing to the between-provenance structural differences inherent in the dataset while the bounded Johnson S_B's provide better fit for many empirical data because of the wide region it occupies on the skewness-kurtosis plane (Egonmwan and Ogana, 2020). Although age, site index (or average dominant height), density and tree height are other variable required for effective development of a yield distribution, the result obtained in this study may serve as a foundation for development of distribution models for the crown and/or crown projection area of the *Parkia* stand, as observed in Ogana and Dau (2019) or used for development of management plan for the plantation. Combining the information contained in this study with the marginal height distribution provides a platform for the derivation of information on volume for the stand, consequently providing routine management plan for the specie.

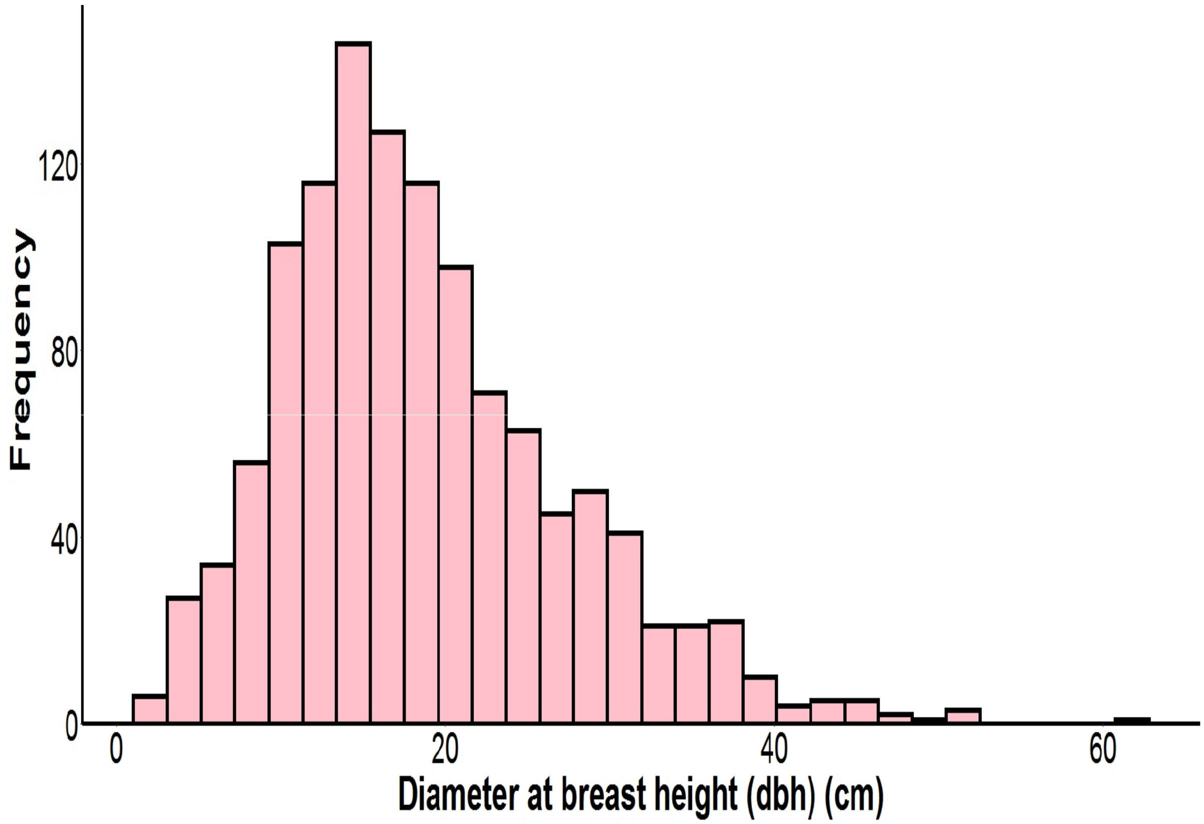

Figure 2: Histogram for diameter measurements of *Parkia biglobosa*

Table 3: Summary for the candidate models

Index	Distribution	Parameter	Selection criterion		Goodness-of-fit test			
					K–S test		A–D test	
			AIC	BIC	D–Value	p–value	A–Value	p–value
M1	Lognormal	$\mu = 2.8144$ $\sigma = 0.4964$	8440.680	8450.850	0.0471	0.0101	4.0882	0.0079
M2	Gamma	$\alpha = 4.6010$ $\beta = 0.2464$	8377.386	8387.556	0.0290	0.2689	0.9867	0.3643
M3	Weibull	$\alpha = 2.2890$ $\sigma = 21.116$	8422.685	8432.855	0.0599	0.0004	5.7460	0.0013
M4	Exponential	$\lambda = 0.0536$	9379.686	9384.771	0.2949	< 0.001	165.7138	< 0.001
M5	Rayleigh	$\sigma = 14.548$	8456.905	8461.990	0.0906	< 0.001	13.2588	< 0.001
M6	Johnson SB	$\gamma = 5.0041$ $\delta = 2.4381$ $\xi = -5.164$ $\lambda = 198.15$	8378.897	8399.237	0.0308	0.2075	0.8166	0.4692

α–level = 5%; D–Value is computed K–S value; A–Value is computed A-D value

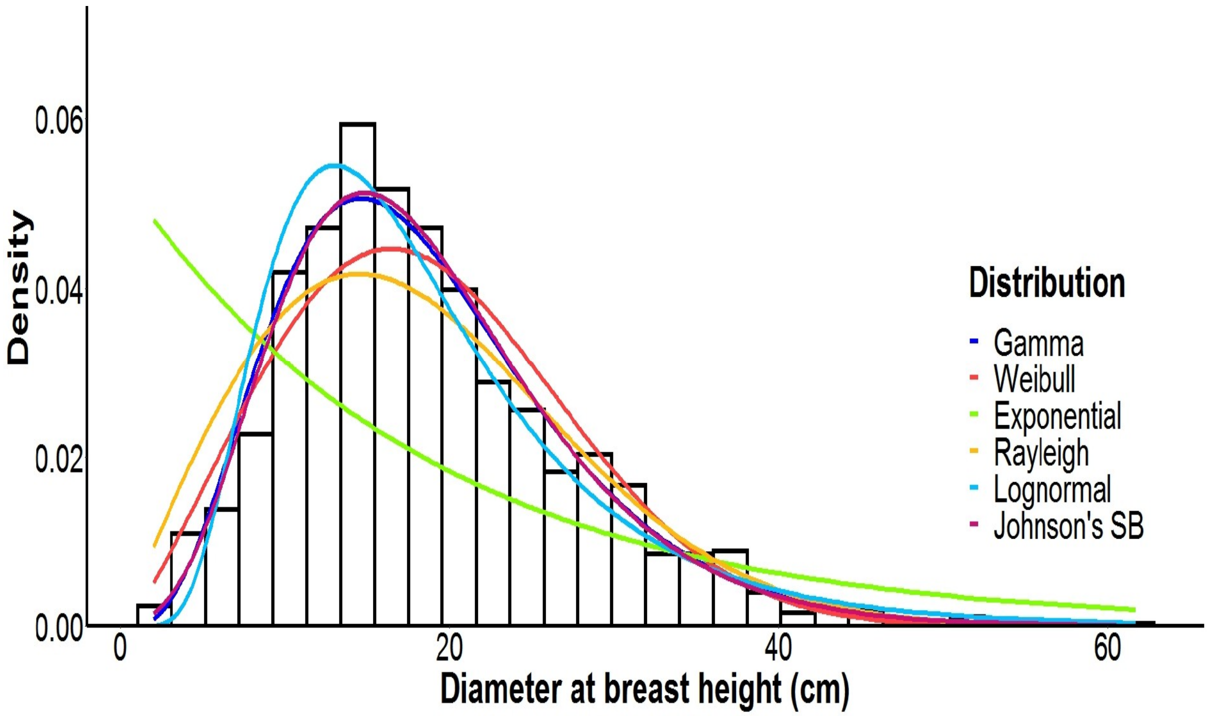

Figure 3: Fit of probability distributions considered

Conclusion

This study reveal that Gamma and Johnson SB distributions can be used for describing the dbh of *Parkia biglobosa* in Wasangare, Saki West Local Government Area of Oyo State, Nigeria. Owing to the smaller Kolmogorov-Smirnov test statistics obtained by the Johnson SB distribution compared to that obtained by the Gamma distribution, the Johnson SB distribution may produce same (or more) flexible estimates as (or than) that of the Gamma distribution. Therefore, fitting dbh of *Parkia biglobosa* for this plantation management purpose(s)may be pursued using Gamma and/or Johnson SB distribution(s).

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