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Modeling diameter distribution for Sakponba Forest Reserve, Edo State, Nigeria

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Key words: Sakponba forest reserve, DBH, Probability density function, Diameter distribution model, Kolmogorov smirnov

Abstract

Tree diameter distributions play an important role in stand performance. Diameter distribution model was developed for Sakponba Forest Reserve. Systematic sampling technique was adopted. A total of 613 trees were measured in 96 sample plots. Diameter at breast height (dbh) at 1.3m above ground data were measured for tree species with dbh ≥ 10cm in the confines of the sampling units. Data collected were analysed using probability density function (pdf), then ranked based on Kolmogorov smirnov. The best six distributions [Log-Logistic (3p), Burr, Dagum, Gen-Logistic, Gen Extreme value and Log normal] were used for fitting the diameter data. The results indicated that the trees in the lower diameter class were more in number than the upper diameter class. Log-Logistic distribution was adjudged more flexible when tested with Kolmogorov smirnov The reason is because the calculated value [Log-Logistic (3P) = 0.04477] was the lowest value and smaller than the tabulated values (D = 0.05 at p ≥ 0.05). This implied that the data followed the specified distribution and that Log-Logistic (3P) can appropriately provide a better fit for the diameter data in Sakponba Forest Reserve.

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Introduction

Tree diameter distributions are essential tool for describing tree population and forest stands. They help to determine the worth of the forests, predict forest growth, plan harvest activities, and thus, enhance forest productivity (Burthart and Tome, 2012). Tree diameter distributions can help deduce past disruption of events, above ground biomass stocks and the status of forest succession (Coomes and Allen, 2007). At species level when they are assessed, they play effective role in providing vital information on regeneration strategies, population trends and demographic rates on specific species. Diameter distributions models statistically fitted help in tree size description. Hence, the magnitude of the tree is evaluated using stem dbh and its frequency distribution is further elaborated using probability distribution functions, also termed as models. Research in tropical forests has shown that there is a small consensus on the flexibility of models.

Amidst so many available models, certain criteria are very pivotal in choosing the most appropriate models. Different types of dbh models data from natural or plantation forests have been used to conduct the assessment. In order to decide on the most appropriate candidate models, some important criteria like interpretability and the number of parameter as well as the presence of the right methods for the estimation of parameters and model comparison are needed. Choosing and practicalizing of appropriate candidates is one sure way to ensure that trees in their environment are conserved and effectively utilized to meet the socio-economic needs of a given state or locality. Several research has shown that Probability density functions (Pdf) have been extensively used in forestry for modelling diameter distribution of trees (e.g., gamma: Nelson, 1964; beta: Zohrer 1972; log-normal; Weibull; Rennolls *et al.*, 1985), although it has been observed that the three-parameter Weibull, SB models and the four-parameter beta are possibly the most frequently used. Weibull distribution has been used for a range of species including beech plantation in Denmark (Nord-Larsen and Cao, 2006), black Spruce plantations in Canada (Newton *et al*, 2005), Chinese Pine in China (Lei, 2008). It has also been used in many growth models based on diameter because of its flexibility and simplicity (Maltamo *et al.*, 2004; *Zhang et al.*, 2003; Liu *et al.*, 2004).

The objective of this study was to select the best model for modeling diameter distributions in Sakponba forest reserve in Edo State.

Materials and methods

Study Area

The study was carried out at BC32/4 in Sakponba Forest Reserve (a secondary natural rainforest) in Edo state Nigeria. The area is located between latitude 6°32¹ and longitude 5° 58ᴵE. The Forest Reserve covers an area of about 32km² with 179 compartments (Edo State Ministry of Environment). The map of the forest reserve is shown in fig-1 of which BC32/4 was selected for this study. The area has an annual rainfall from 2078mm to 4, 000mm per annum and mean of minimum and maximum annual temperature of 27°C and 32°C respectively, while the relative humidity ranges from 70% to 80%. (Edo State Ministry of Environment). The soil type in the area is sandy loam.

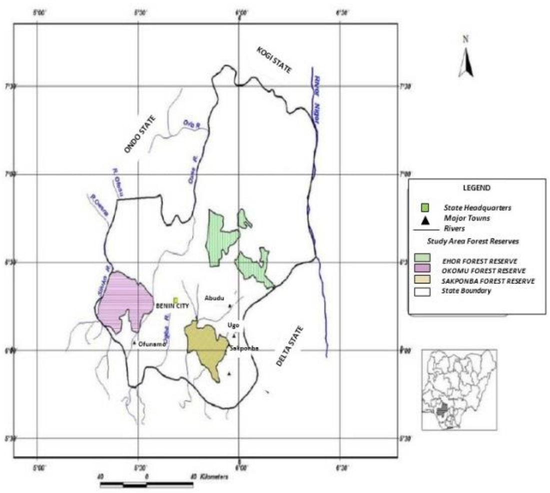


Fig. 1. Map Sakponba Forest Reserve, Edo State.

Data Collection

This study involved the inventory of trending species in the study area. The dbh of the adult trees in each sample plot were measured using diameter girth tape.

The Systematic sampling techniques was adopted for the data collections. This method involved four (4) blocks in the forest reserve. Each block consisted 200m×200m along the base line. Every block consists of sixteen (16) sample plots of 50m×50m. Six (6) sample plots were randomly selected in each block.

Each block therefore comprised of six (6) sample plots with a total of (1½ha) hectares. Implying that an area of 60, 000m² (6ha) was assessed for the adult trees. All trees above 10cm diameter were considered for measurement within the sample plots.

Data were analysed by EASY FIT 5.5®. Mean, median, standard deviation and range changes were calculated using descriptive statistics and histograms were drawn.

Data Analysis

Fitting of diameter Distribution Model

In this study, various distribution models were tried using Kolmogorov Smirnov goodness of fit to rank them accordingly. Relatively, six best ranked distribution models were chosen to fit the diameter distribution data. In other words, the distribution used for fitting the dbh data were Log-Logistic (3P), Burr, Dagum, Gen-Logistic, Gen Extreme value and Lognormal.

Estimating Parameters for Diameter Distribution Models

Parameters for diameter distribution model were estimated using easy fit 5.5® software. The (pdf), cumulative distribution function, survival function, hazard function and cumulative hazard function were all equally analysed by easy fit 5.5® software. The statistical distribution models considered were represented below:

Table 1. Statistical distribution models considered in the study.

Distribution	Models	Parameter
Log-Logistic (3P)	$f(x)=\frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}\left(1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{-2}$	α = Shape (α > 0), β = Scale (β > 0) and γ = Location (γ ≡ 0
Burr	$f(x)=\frac{\alpha k\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}}{\beta\left(1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{k+1}}$	k = Shape (k > 0), α= Shape (α > 0), β = Scale (β > 0) and γ = Location (γ ≡ 0)
Dagum	$f(x)=\frac{\alpha k\left(\frac{x-\gamma}{\beta}\right)^{\alpha k-1}}{\beta\left(1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{k+1}}$	k = Shape (k > 0), α= Shape (α > 0), β = Scale (β > 0) and γ = Location (γ ≡ 0)
Gen. Logistic	$f(x)=\frac{(1+kz)^{-1-\frac{1}{k}}}{\sigma\left(1+(1+kz)^{-\frac{1}{k}}\right)^{2}}\ k\neq 0$ $f(x)=\frac{exp(-z)}{\sigma(1+exp(-z))^{2}}\ k=0$ Where $z\equiv\frac{x-\mu}{\sigma}$	k = Shape, σ = Scale (σ > 0) and μ = Location
Gen. Extreme Value	$f(x)=\frac{1}{\sigma}\,exp\left(-(1+kz)^{-\frac{1}{k}}\right)(1+kz)^{-1-\frac{1}{k}}\ k\neq 0$ $f(x)=\frac{1}{\sigma}\,exp(-z-\exp(-z))\ k=0$ Where $z\equiv\frac{x-\mu}{\sigma}$	k = Shape, σ = Scale (σ > 0) and μ = Location
Lognormal	$f(x)=\frac{exp\left(-\frac{1}{2}\left(\frac{\ln(x-\gamma)-\mu}{\sigma}\right)^{2}\right)}{(x-\gamma)\sigma\sqrt{2\pi}}$	σ = Shape (σ > 0), μ = Scale and γ = Location (γ ≡ 0)

Results

Diameter Distribution Model

The summary of the descriptive statistics and goodness of fit of diameter distribution functions for Sakponba Forest Reserve were presented on Tables 2 and 3. The value of the skewness was 2.5077 while that of excess kurtosis (leptokurtic curve) was 0.32903 (Table 2). The goodness of fit of the distributions were tested with Kolmogorov smirnov as shown in Table 3.

Table 2. Summary of Descriptive Statistics for Dbh Class in Sakponba Forest Reserve.

Statistics	Value	Percentile	Value/cm
Sample Size	613	Min	21
Range	300	5%	56
Mean	85.956	10%	61.4
Variance	685.51	25%	71
Std. Deviation	26.182	50%	83
Coef. of Variation	0.3046	75%	93
Std. Error	1.0575	90%	113
Skewness	2.5077	95%	126
Excess Kurtosis	0.32908	Max	126

Table 3. Summary of Goodness of Fit of Distribution Functions for Sakponba Forest Reserve.

SL	Distribution	Kolmogorov Smirnov	
		Statistic	Rank
1	Log-Logistic (3P)	0.04477	1
2	Burr	0.04558	2
3	Dagum	0.04718	3
4	Gen. Logistic	0.05106	4
5	Gen. Extreme Value	0.05867	5
6	Lognormal	0.08691	6

Table 3 showed the Summary of Goodness of Fit of Distribution Functions for Sakponba Forest Reserve with Log-Logistic (3P) model ranking first and Log normal last among the first six models selected.

Fig. 2 showed that the distribution pattern of the dbh (m) of trees in Sakponba forest reserve was positively skewed while Table 4 showed the parameter values of the six distribution functions.

The graphs of observed and estimated probability functions of dbh class of the distribution functions showed that there is no significant difference ($p > 0.05$) between the empirical and theoretical cumulative functions (Figs. 3a – f). This means there is no difference between the observed and predicted diameter frequencies.

Table 4. Distribution Parameter Estimates for Sakponba Forest Reserve.

SL	Distribution	Parameters
1	Log-Logistic (3P)	α=7.05 β=70.114 γ=10.456
2	Burr	k=0.69735 α=9.3834 β=75.89
3	Dagum	k=1.2965 α=7.493 β=76.839
4	Gen. Logistic	k=0.20758 σ=10.047 μ=80.068
5	Gen. Extreme Value	k=0.05775 σ=14.724 μ=74.29
6	Lognormal	σ=0.24862 μ=4.3448 γ=4.0665

Table 5 showed the Dbh frequency distribution in the observed diameter class which was evaluation with Log-Logistic (3P) distribution in Sakponba Forest Reserve.

Table 5. Dbh frequency distribution in the observed diameter class evaluated with Log-Logistic (3P) distribution in Sakponba Forest Reserve.

Size class (cm)	Observed/ha	Predicted/ha
≤10	0	0
11 - 20	0	0
21 - 30	26	55
31 - 40	22	13
41 - 50	25	14
51 - 60	10	8
61 - 70	9	3
71 - 80	2	2
81 - 90	25	2
91 - 100	3	4
> 100	35	5

The result of table 6 showed that there is no significant difference between the observed and predicted using the T-test.

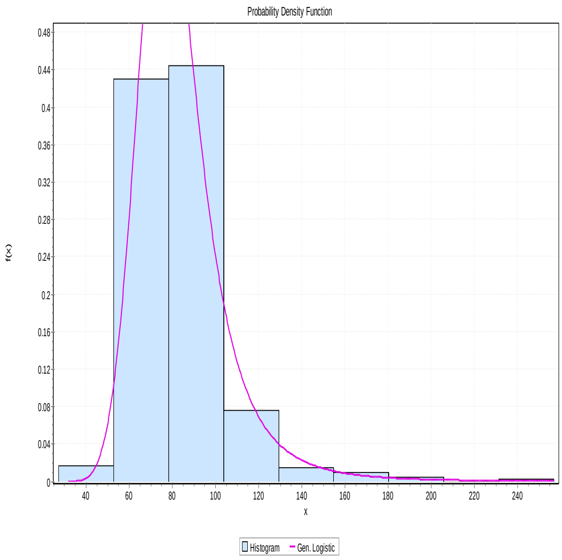
Table 6. Paired Two Samples for Means.

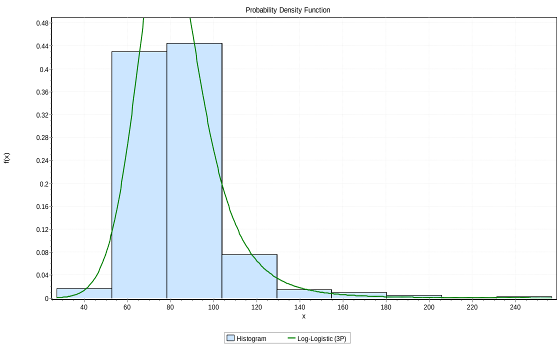
	Observed	Predicted
Mean	9.272727273	9.272727
Variance	100.0681818	349.4182
Observations	11	11
Pearson Correlation	0.484612475	
Hypothesized Mean Difference	0	
Df	10	
t Stat	0	
P(T<=t) one-tail	0.5	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	1	
t Critical two-tail	2.228138852	

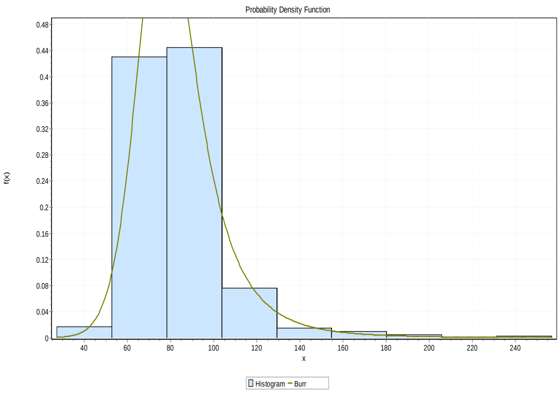
Forest Reserve

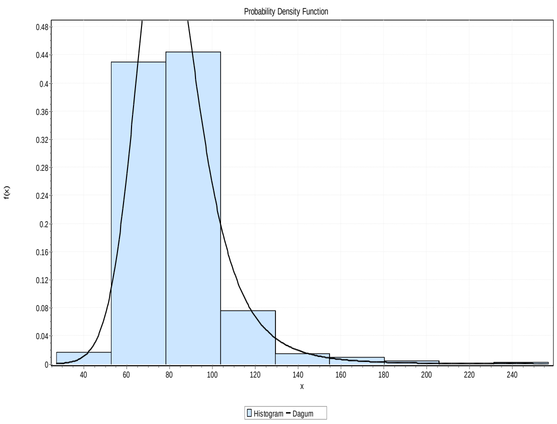
Table 5 showed the distribution's account results of 613 trees in the observed diameter class and their evaluation with Log-Logistic (3P) probability distribution at 10cm dbh class interval. The result of the predicted dbh frequencies (Table 5) showed that there were more trees in the lower dbh class than in the upper dbh class.

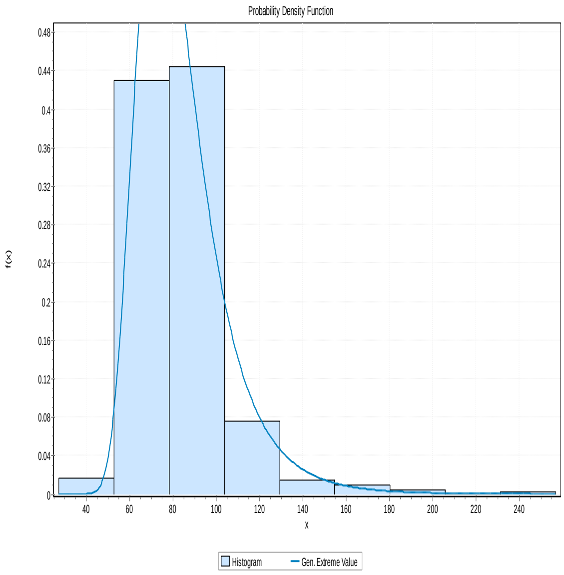
The T – test conducted for the observed and predicted dbh frequencies indicated that the t – statistic of 0.05 was less than the critical level of 1.825 and 1.000; 2. 2281 for one- tail and two-tail respectively, meaning, there is no significant difference ($p > 0.05$) between the observed and predicted dbh frequencies. Similar results were reported by Ige *et al.*, (2013), in Onigambari Forest Reserve, Nigeria and Fallahchai and Hashemi (2011), in North of Iran forest











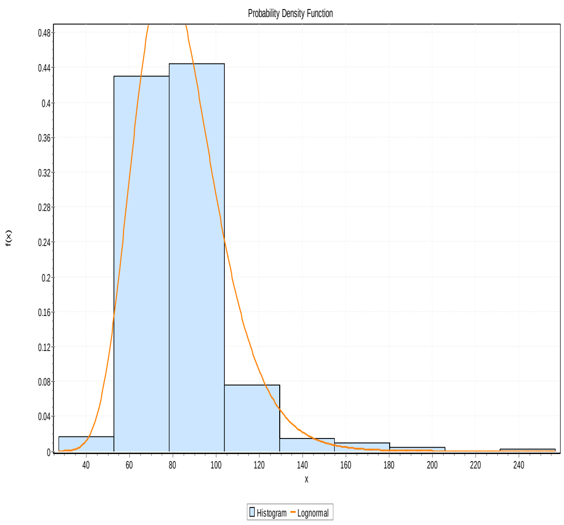


Fig. 2. DBH Distribution pattern of the various distributions in Sakponba Forest Reserve.

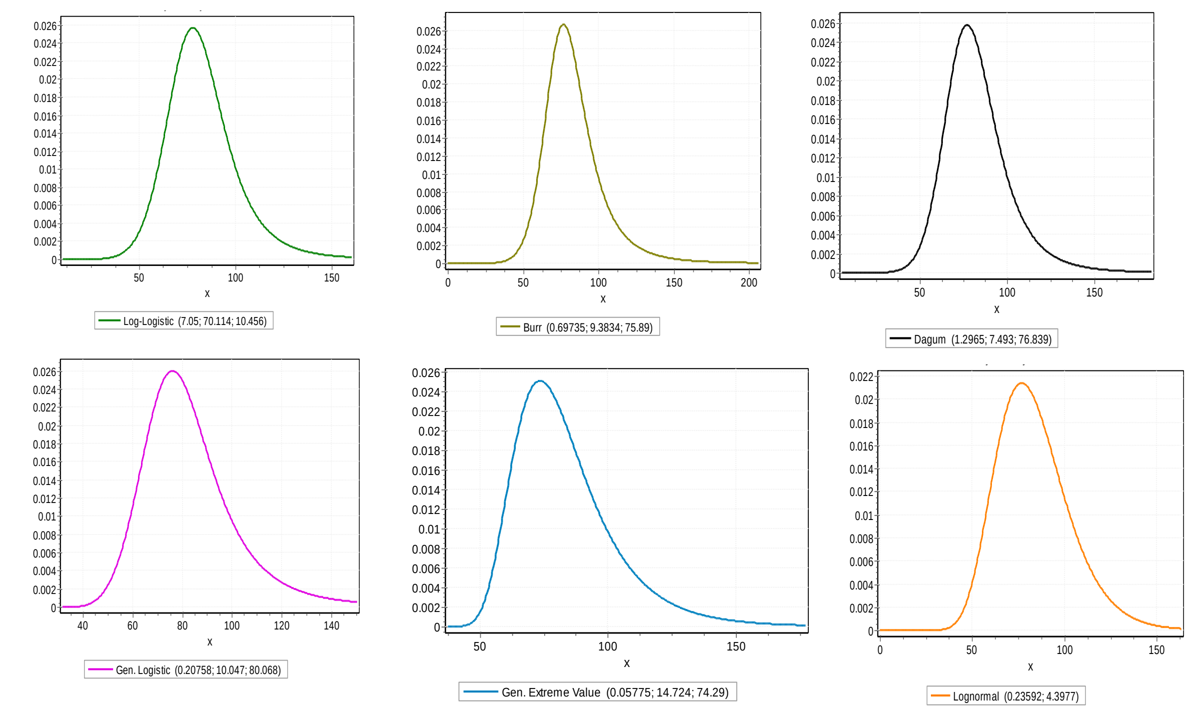


Fig. 3. (a) Log-Logistic (3P); (b) Burr; (c) Dagum; (d) Gen-Logistic; (e) Gen.Extreme value and (f) Lognormal graphs of observed and estimated probability function of dbh class for Sakponba.

Discussion

High positive skewness and peakedness means that considerable numbers of trees were concentrated in the lower diameter classes (Gadow, 1983). The goodness of fit of the distributions was tested with Kolmogorov smirnov as shown in Table 3. Based on ranking, six distributions were selected. The Kolmogorov smirnov test indicated that the first three distributions can provide good fits for the diameter data, because their calculated D-values (Log- Logistic (3P): 0.04477: Burr: 0.04558; Dagum: 0.04718; were less than their tabulated D-value (0.05). This implied that the null hypotheses were accepted for these three distributions, meaning the data followed the specified distribution. While Gen Logistic; 0.05106: Lognormal: 0.08691 and Gen Extreme Value: 0.05867 were greater than their tabulated D-value (0.05) which implied that the null hypotheses were rejected for these three distributions, meaning the data did not follow the specified distribution. However, Log-Logistic (3P) distribution was more flexible in fitting the diameter data when tested with Kolmogorov smirnov because it has the lowest calculated D-values. Raimundo *et al.*, (2017) stated that Log Logistic model were efficient in delineating the productive differences in their study area. The good performances of Log-Logistic were demonstrated in natural (Podlaski 2006) and plantation forests (Nanang, 1998). Renato *et al.* (2014) stated that at the subplot level, Log- logistic did better in their study. It also had the best fit to the data and provided reasonable fits for 94.5% and 87.5% of the subplots and species at the same threshold level. They further noted that it had the widest coverage of the skewness- Kurtosis space.

This pattern indicated that the forest has trees more in the lower dbh class that is adequate enough to replace trees in the upper dbh class in the future (i.e. when the big trees are harvested or when they die). This finding is consistent with previous reports from the research for two other tropical rainforests (Boubli *et al.,* 2004; Bobo *et al.,* 2006). Adekunle (2002) also reported positive skewness distribution pattern for Ala and Omo Forest Reserves in Nigeria. This implied that the forests are still undergoing regeneration and recruitment, which are crucial indicators of forest health and strength (Jimoh *et al.* (2011). The gently rising diameter distribution which falls gradually at the end obtained in the study as shown in fig. 2, is typical of an uneven aged stands in the results obtained by Adekunle on (2002) in his study on natural tropical forest ecosystem of Nigeria.

The graphs of observed and estimated probability functions of dbh class of the distribution functions showed that there is no significant difference ($p > 0.05$) between the empirical and theoretical cumulative functions (Fig. 3a-f). This means there is no difference between the observed and predicted diameter frequencies.

Conclusion

The diameter distribution model was successfully estimated using the graph of probability density function that confirmed the expected frequencies in each dbh class. Using appropriate probability theories to predict trees distribution in tropical rainforest is important in the estimation of productivity in different dbh class. In this study, probability distributions were applied to estimate the diameter distribution, and statistical methods were used to provide diameter distribution models.

Log-Logistic (3P) distributions was more flexible in fitting the diameter data in Sakponba Forest Reserve when tested with Kolmogorov smirnov. In one case a particular distribution model will be found empirical to give the best fit, whilst in another case another model will be found to be empirically best. The most appropriate way to meaningfully talk about the best distributional model with regard to the most flexible models is in representational terms. Diameter distribution model reveal structure of stand or forest and its development is therefore recommended for application in planning silvicultural treatment in Sakponba Forest Reserves. More studies are therefore recommended to achieve more applied results.

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