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Modeling Tree Diameter Distributions in Arboretum of Forestry and Wildlife University of Uyo: An Evaluation of 8 Statistical Models

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I. Introduction

The diameter of a tree provides a measure of tree performance and is a useful starting point for estimating tree height and volume. Diameter distribution is an efficient indicator of forest growth and most powerful way to describe the properties of a stand. They have direct effect on the choices concerning silvicultural and harvesting stages activities.(Robson *et al.,* 2016, Ekpa et al., 2014, Zira and Ghide, 2013, Robson and Hamann, 2011. There are different fitting methodologies that have been used to model diameter distributions. These include Lognormal, Weibull and Johnson SB, Generalized pareto, Weibull, Log-logistic, Generalized gamma, Johnson SB, Dagum, Frechet and Erlang distribution functions. Very few of these models are classic models frequently applied for diameter distribution analysis in tropical forest (Bailey and Dell 1973, Rennolls *et al.,* 2007, Burkhart and Tome 2012).

Arboretum of the Department of Forestry and Wildlife, University of Uyo was established purely for research purpose. Lots of researches have been carried out in the arboretum(Etigale *et al.,* 2014, Ijeomah *et al.,* 2014) but unfortunately, no research were carried out to establish a model for diameter of teak trees .

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Teak (*Tectona grandis*) is a high value furniture wood being grown in plantations around the world. Teak is relatively easy to establish in plantations and, because of the demand for teak wood products, it has good economic prospects as a plantation species for fine woods. Teak is indigenous to India, Myanmar, Thailand and Laos. Its range is tropical, occurring between latitudes 25°N and 9°N (White, 1991). *Tectona grandis* L.F belongs to the family of *verbenaceae.* It is one of the most important and celebrated timber species of the Tropics (Katwal *et al.,* 2001). Its utilization benefits of workability, durability, attractiveness and strength has qualified it as one of the world best grade timber (Jackson 1994). Thus, there is the need to manage it.

This work therefore aims to model the diameter structure of teak in the arboretum and to select suitable distributions by means of fitting of probability density function. It is hoped that the results will serve as a useful input in management of the arboretum.

II. Materials And Methods

a) *Study area*

The study was carried out in the arboretum of the Department of Forestry and Wildlife, University of Uyo. Uyo lies between latitudes 4º58´and 5º05´ and longitude 7º54´ and 8º00´E. The area is within the tropical rainforest zone of Nigeria. It has a mean annual rainfall of about2, 581mm and an average of 165 rain days per annum. Mean annual temperature varies between 27 and 28ºC, while the humility in the area varies between 60% and 83%, with the lowest and highest value recorded in January and August, respectively (Ekanem, 2010)

The natural vegetation of the area is tropical rainforest characterized by emergent with multiple canopies. Some of the most commonly found trees in the area include Gmelina *arborea* Cassia species, Lovoa weineana, Mammea Africana, Pterocarpus species, Mimusops djave, and Nauclea diderrichii.

b) *The data*

Data were collected through direct enumeration and mensurement of individual trees (over bark) at breast height(1.3m above ground, dbh) of tectona grandis in its compartment. The measurements were done by winding the diameter tape round each tree. Eight distribution functions were fitted to the diameter data obtained. The probability density functions (pdf) for the distribution are:

Generalized Pareto distribution

$$f(x) = \frac{1}{\sigma}\left(1 + k\left(\frac{x-\mu}{\sigma}\right)\right)^{-1-\frac{1}{k}} ; k \neq 0 \qquad \text{Equation 1}$$

Weibull (3P) distribution

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1} \exp\left[-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right] \qquad \text{Equation 2}$$

Log–Logistic (2P) distribution

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1}\left(1+\left(\frac{x}{\beta}\right)^{\alpha}\right)^{-2} \qquad \text{Equation 3}$$

Generalized Gamma (4P) distribution

$$f(x) = \frac{k(x-\gamma)^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)} exp\left[-\left(\frac{x-\gamma}{\beta}\right)^{k}\right] \qquad \text{Equation 4}$$

Johnson SB distribution

$$f(x) = \frac{\delta}{\lambda\sqrt{2\pi}\, z(1-z)} exp\left\{-\frac{1}{2}\left(\gamma + \delta Ln\left(\frac{z}{1-z}\right)\right)^{2}\right\}$$

$$where\ z = \frac{x-\xi}{\lambda} \ldots\ldots \text{Equation 5}$$

Dagum (4P)

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

Frechet (3P)

$$f(x) = \frac{\alpha}{\beta}\left(\frac{\beta}{x-\gamma}\right)^{\alpha+1} exp\left[-\left(\frac{\beta}{x-\gamma}\right)^{\alpha}\right] \ldots\ldots \text{Equation 7}$$

Erlang (3P)

$$f(x) = f(x) = \frac{(x-\gamma)^{m-1}}{\beta^{m}\Gamma(m)} exp\left[-\left(\frac{x-\gamma}{\beta}\right)\right] \ldots\ldots \text{Equation 8}$$

where x = variable (diameter at breast height), α = shape parameter, β = scale parameter, γ = location parameter.

To fit the distribution to the diameter data, EasyFit 5.5 software was used. Easy Fit is probability distribution fitting software for Windows. It provides a complete set of features which allows the user to fit probability distributions to data, analyze the results and select the model which best describes the data.

III. Results and Discussion

The summary of the descriptive statistics and goodness of fit of diameter distribution for University of Uyo forest arboretum are presented on Table 1 and 2. The results shows the diameter at breast height data with mean 16.83, standard error 1.08, skewness 1.96 while that of excess kurtosis is 4.84 (Table 1). High positive skewness and peakedness means that considerable numbers of trees are concentrated in the lower diameter classes (Gadow, 1983). In addition, it indicates the presence of suppressed trees. Function fit assessment was based on Kolmogorov-Smirnov test value, the function providing the lowest values (0.0969) being considered the best function. Results of the Kolmogorov-Smirnov test for function fitting are provided in Table 2. Eight distribution functions were selected for ranking. The Kolmogorov-Smirnov tests indicate that these distributions can provide good fits for the diameter data.

Table 3 shows the parameter values of the eight functions of Teak trees in the arboretum while Figure 1 shows the graphs of observed and estimated probability function of dbh class for the arboretum. Greater percentage of the trees were in their lower dbh class (10-20cm) that is sufficient enough to replace trees in the upper dbh class in the future. Boubli *et al.,* 2004; Bobo *et al.,* 2006 also reported positive skewness distribution pattern in their studies. This implies that forest are still undergoing regeneration and recruitment, which are vital indicators of forest health and vigor(Jimoh *et al.,*2011).

In addition to ranking, fitting quality may be attested by the frequency histograms (Figure 1). If the diameter distribution depicts a single peak with distortion of the density concentration to the left, this pattern must be kept despite silvicultural interventions (Rubin et al., 2006, Podlaski and Zasada 2008, Zheng and Zhou 2010). Some species stood out by the higher number of individuals within the initial classes, which defines the distribution as 'inverted-J' type. This may be attributed to high density of the specie; also it could be as a result of the stand not had been thinned.

Generalized Pareto and Weibull function provided more satisfactory values for the Kolmogorov-Smirnov test. Weibull distribution have been analyzed and affirmed to be flexible by Bailey and Dell, 1973, Quang, 2004, Ekpa, 2014, Eder, 2010, and Shamaki *et al* (2019). This study shows that other than the Weibull function, other functions can be used to describe the diameter structure of stands.

Nevertheless, all functions being analyzed in this study provided satisfactory results for use in growth and yield modeling of Teak stands in the arboretum thus, they can be used as a pattern in order to planning and scheduling for stands to establish stable and resistant forests with maximum biological production.

IV. Conclusion

Effective forest management planning requires timely and reliable information on forest development. Reliable information is very crucial and fundamental to sustainable management. Diameter distributions are important decision marking tools for stand management. In this study, different distribution models were used to characterize diameter of *tectona grandis* in university of Uyo arboretum, the stands showed diameter distribution with decreasing exponential curves. Greater percentage of the trees were in their lower diameter class, this may be attributed to high density of the species also as a result of the stand not had been thinned. Generalized pareto and Weibull function provided more satisfactory values for Kolmogorov-Smirnov test. The models can be used as a preliminary tool in scheduling silvicultural treatment in the arboretum. It will be ecologically and economically favorable to carry out selective thinning on large trees so that the undergrowth can develop to encourage stem diameter increment and so reach a useable size sooner.

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Table 1: dbh class for University of Uyo forest arboretum

Statistic	value
Minimum value	9.55
Maximum value	43.60
Range	34.05
Mean	16.83
Variance	56.41
Coefficient of Variation	0.45
Standard Error	1.08
Skewness	1.96
Kurtosis	4.84

Table 2: Kolmogorov-Smirnov test for the tested functions

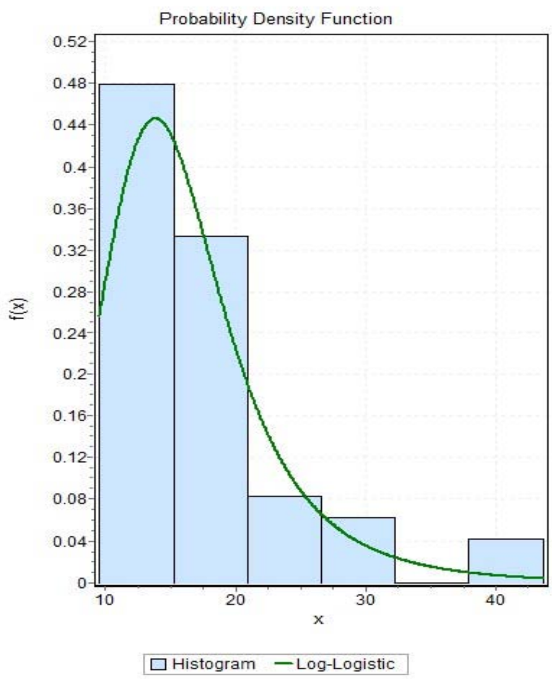
S/N	P.d.f	Kolmogorov - Smirnov	
		Statistic	Rank
1	Dagum (4P)	0.1207	6
2	Erlang (3P)	0.1237	8
3	Frechet (3P)	0.1215	7
4	Generalized Gamma (4P)	0.1185	4
5	Generalized Pareto	0.0969	1
6	Johnson SB	0.1185	5
7	Log-logistic (2P)	0.1053	3
8	Weibull (3P)	0.0988	2

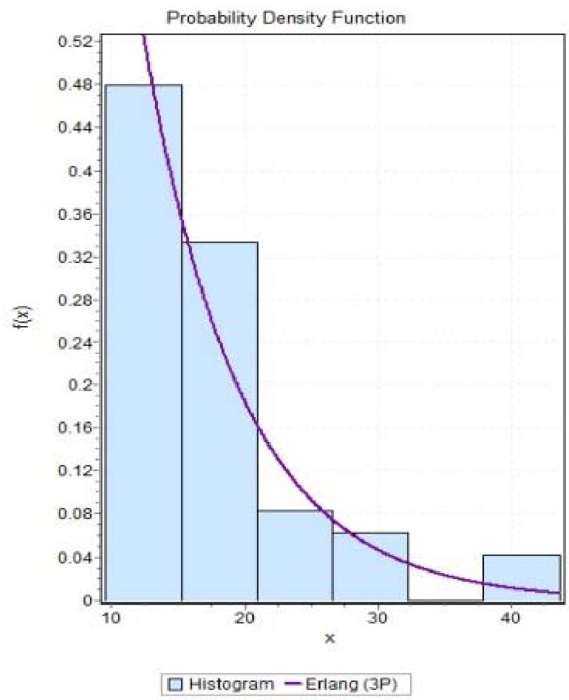
Numbers in parentheses refer to the amount of parameters being used

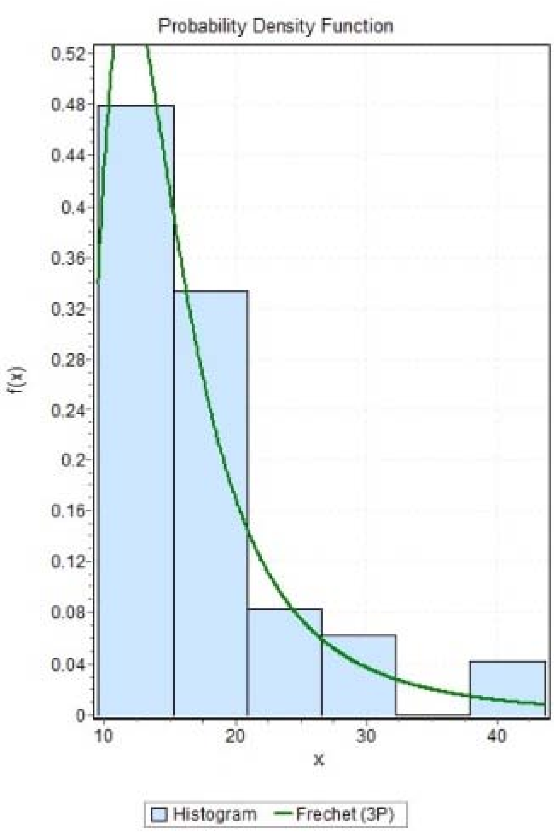
Table 3: Distribution Parameter Estimate for Teak in the Arboretum

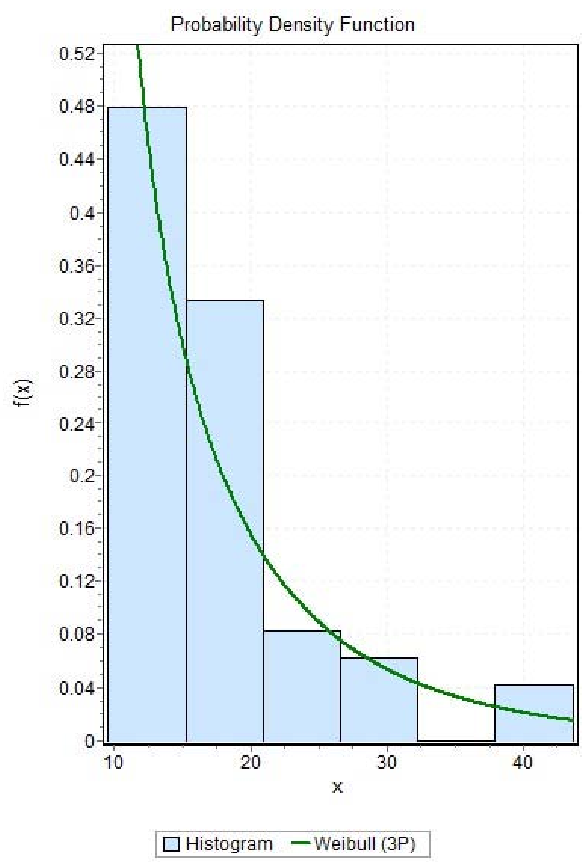
S/N	p.d.f	Parameter value
1	Dagum (4P)	k=77.671,α=2.6355, β=1.9456, δ2.8377
2	Erlang (3P)	m=1, β=7.2777, δ=9.55
3	Frechet (3P)	α=2.8123, β=10.83,δ=2.1477
4	Generalized Gamma (4P)	k=0.77137, α=0.93819,β=7.9583, δ=9.55
5	Generalized Pareto	k= –0.0483, σ =8.1046, μ =9.0974
6	Johnson SB	δ=2.2316,α=0.91737,λ=68.093,ξ=8.8876
7	Log-logistic (2P)	α = 4.5726, β=15.25
8	Weibull (3P)	α =0.81387, β 7.6266, δ= 9.55

Numbers in parentheses refer to the amount of parameters being used, ***α*** *= shape parameter,* ***β*** *= scale parameter and* ***γ*** *= location parameter.*


Probability Density Function
f(x)
x
Histogram
Log-Logistic


Probability Density Function
f(x)
x
Histogram
Erlang (3P)


Probability Density Function
f(x)
x
Histogram
Frechet (3P)


Probability Density Function
f(x)
x
Histogram
Weibull (3P)

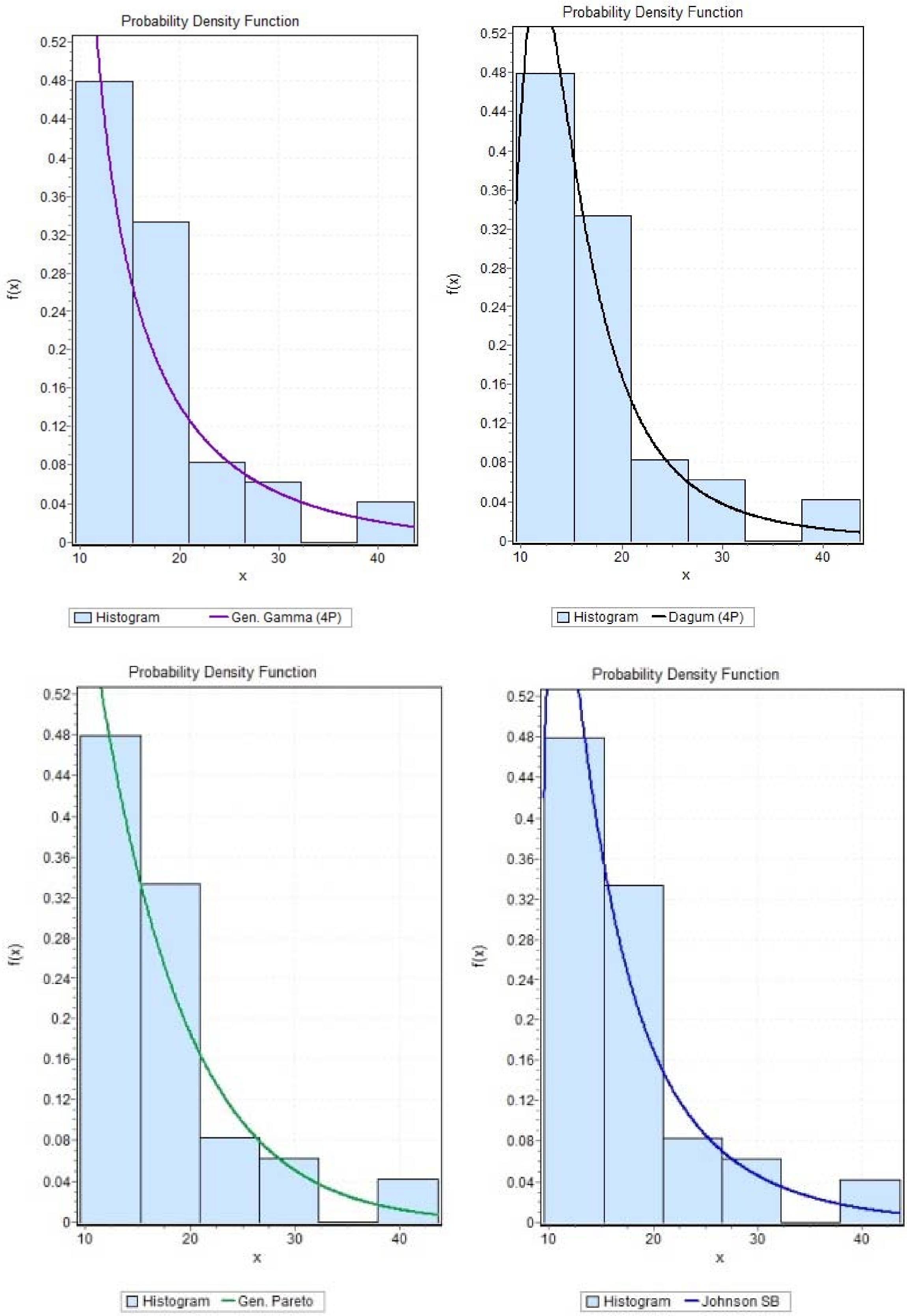


Figure 1: Graphs of observed and estimated probability function of dbh class for the arboretum