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Full Length Research Paper

Gmelina arborea Roxb. Graded Stands with the Weibull Distribution Function in Oluwa Forest Reserve, Nigeria

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The diameter distribution of growing stock is an essential starting point in many forest management planning problems. The three-parameter Weibull distribution model was used to grade the diameter classes of *Gmelina arborea* plantation in Oluwa Forest Reserve located in the tropical rainforest area of Nigeria. Data used for the study were diameter at breast height (dbh) taken at five years interval. The interval ranging from 11,16, 21, 26, and 31 years of plantation establishment. Quadratic mean dbh exhibited a strong linear relationship with Weibull parameters 'a' and 'b' and mean height exhibited a strong linear relationship with parameter 'c'. Validation test carried out on the quadratic dbh and Weibull parameter relationship further proved that the models were consistent and efficient and were therefore recommended for predicting the diameter distribution of the stand.

Key words: *Gmelina arborea,* diameter distribution, Weibull distribution function, plantation, Nigeria.

INTRODUCTION

Of all the many and varied natural ecosystem found on the earth, perhaps the most inspiring and popular are the tropical rainforests. These forests, with their large trees and extraordinary flora and fauna constitute the planet's richest habitats, and one of our most precious natural resources (Longman and Jenik, 1990; Okojie, 1994). The diversity of trees found in the tropical rain forests is quite extraordinary, and far exceeds that of any other kind of forest, the tree species ranging from Khaya spp, *Miliciaexcelsa, Nauclea diderrichii* and *Gmelina arborea*, etc. The living environment continues to experience changes across the world because man has caused profound environmental changes in his search for survival and development. These have brought great pressure on the remaining tropical rainforest thereby leading to over-exploitation of several timber species. Again, the need to solve the problem of wood and wood products supply deficits has led to the establishment of forest plantations with exotic and indigenous tree species (Evans, 1998; Carnus *et al.,* 2003; Evans and Turnbull, 2004). Of all the exotic timber species grown in plantations, *Gmelina arborea* has been practically promising yet in an attempt to ensure steady production wood in right quantity and quality, appropriate management practice is essential. To manage the existing forest in a sustainable manner, adequate planning based on reliable information of trees and stand condition are required. One of such information is the number of trees in specific size classes, which enable the forest managers to decide on specific end – use for the trees (Akindele, 2002).

The ability to predict the distribution of diameter in a stand is essential for foresters to make wise management decisions. Knowledge of diameter distribution by size classes forms the basis for decision making as to when a stand can be economically harvested for a given end product. A number of different distribution functions have been used to model diameter distributions, including Beta, Lognormal, Johnson's Sb, and Weibull. In analysis of the suitability of most of these functions for grading diameter distribution, the Weibull distribution, (Bailey and Dell ,1973) as a model for diameter distributions, has been applied extensively in forestry due to its ability to describe a wide range of unimodal distributions including reversed-J shaped, exponential, and normal frequency distributions, and the relative simplicity of parameter estimation (Bailey, Dell 1973; Mabvurira *et al*., 2002). These special qualities gives Weibull a good edge over other distribution models for

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stem-diameter distribution studies.
This distribution is a three-parameter distribution defined by the probability density function:

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

For $x \geq a$

$While the cumulative function is given as$

$$f(x) = 1 - exp\left(-\left(\frac{x-a}{b}\right)^{c}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

For $x \geq 0$
Where:
a = location parameter,*b* = Scale parameter,*c* = Shape parameter.
This explains why most of the recent work on diameter distribution has used this function, as evidenceby the example quoted above.
In this study, the Weibull distribution is applied to model the diameter distribution of *Gmelina arborea* based on the data obtained from the plot of species in the Plantation. It is that the result will be a useful input in predicting stand yield.

MATERIALS AND METHODS

The data used in this study were plot data of *Gmelina arborea* plantation in Oluwa Forest Reserve in the humid tropical zone of Southwestern Nigeria. Oluwa forest reserve is located in Odigbo Local Government Area and is situated between latitude 6º55´ and 7º20´N and longitude 3º45´ and 4º32´E with an area of 87,816 ha (Adeduntan, 2009).Annual rainfall ranges from 1700 to 2200 mm and annual temperature is 26°C, with mean elevation of 123m above sea level (Onyekwelu *et al.*, 2006). Plantation trail in Oluwa began in early 20th century but larger scale plantation establishment started in the 1960s.Over the years, *Gmelina arborea* has emerged as the dominant plantation species in Oluwa, accounting for about 89% total plantation (Onyekwelu, 2001).Five different stands of varying age series were selected. 1980, 1985, 1990, 1995, 2000. Data for diameter distributions included sample plots from five stands of 20m x20m.The enumeration involved diameter measurement of individual trees (over bark) at breast height (1.3m above ground, dbh).
A three-parameter Weibull distribution was fitted to the dbh-class frequency data for each year of assessment using a statistical application software package known as EASY FIT **5.5**. The relationships between the estimated Weibull parameters and mean dbh as a stand growth attribute were examined. Thereafter, regression models for predicting each of the Weibull parameters from the stand growth attribute were fitted.

The fitness of the models developed was evaluated according to Significance of Regression (F ratio), Root Mean square Error and Coefficient of Determination (r^2).The models were further subjected to validation tests based on Reynolds *et al.,* (1981) and Cooper and Weekes (1983). The validation test for this study was such that the original data were split into two sets; the first called the calibrating set (variables in their original and transformed forms) and the second the validation set. The part ‘a’ data for all the year of assessment were pooled together and used for the construction of the models while the validation of the model was done using the data from part ‘b’ known as the validation data sets. The constructed models were used to predict the values of Weibull parameters known as expected values. To validate the equations, the predicted values were compared with the observed values (validation set), by using the student t-test for paired means, to check for significant difference the two sets. Models that were based on data sets that exhibited no significant difference ($p< 0.05$) were accepted as valid

RESULTS AND DISCUSSION

The frequency distribution size class distribution of the plots data used in the study is presented in Figure 1.Having fitted the three-parameter in Weibull function to the diameter distribution data, parameter values obtained are shown in Table 1. The linear correlation coefficient between the Weibull parameters and the stand attributes are presented in Table 2.All the three Weibull parameters varied at different periods of assessment.

The location parameter ‘a’ ranged between 1.97 to 3.0206, scale parameter ‘b’ ranged between 19.844 to 31.446 and the shape parameter ‘c’ ranged from 1.2463 to 5.3058.The shape parameter(c) is very important in size class distribution studies since it describe the distribution curve (Adegbehin, 1985).A value of c > 1 is indicative of unimodal distribution curve which is typical of even-aged stand structure (Rustagi, 1978).The normal distribution curve has c value of 3.6. Unimodal curves with c < 3.6 are said to be negatively skewed, while those with c > 3.6 are positively skewed (Okojie 1981; Adegbehin 1985).

The linear correlation coefficients between the Weibull parameters and the stand attributes showed that there was strong correlation between quadratic mean dbh and Weibull parameters ‘a’ and ‘b’ and also a strong correlation between mean height and Weibull parameter ‘c’. The relationship was positive for location and scale parameters and negative for shape parameter. Of the entire stand attributes considered, diameter square had the weakest linear relationship with each of the Weibull parameters. Following several iteration, the best regression equations for estimating the Weibull parameters from stand growth attributes are as follows

$$a = 0.19Dq - 2.74 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

(r^2 = 75.74%; RMSE = 0.28; F = 9.37)

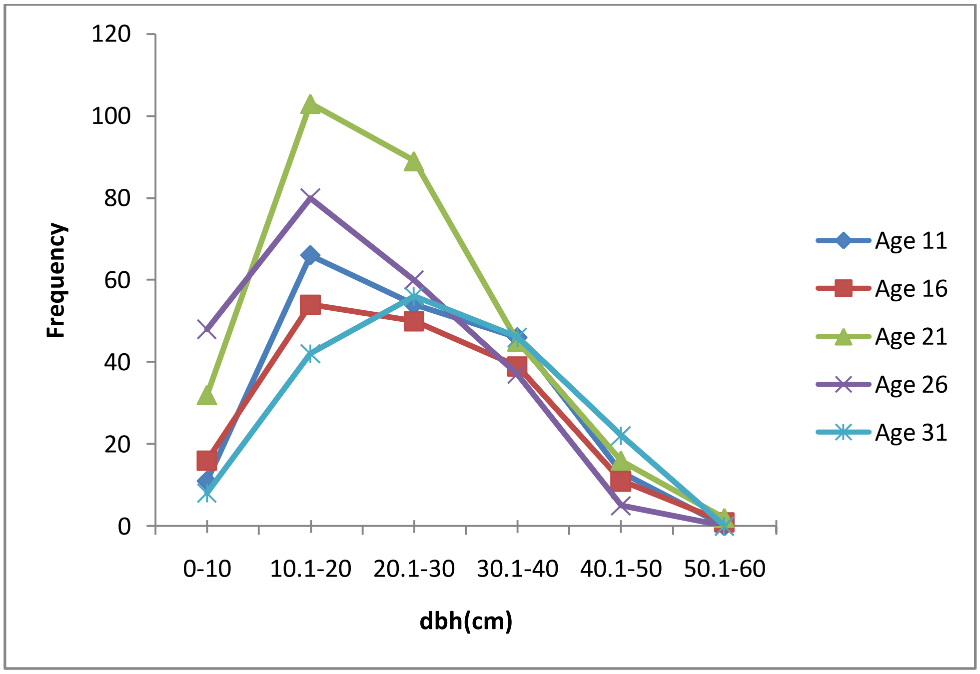

Figure 1. Diameter Distribution of *Gmelinaarborea* in Oluwa Forest Reserve.

Table 1. Estimated Weibull Parameters.

Age	A	B	C
11	1.97	21.737	5.3058
16	2.1659	23.48	3.1379
21	2.0225	21.225	3.8396
26	1.7222	19.844	2.3945
31	3.0206	31.446	1.2463

a = location; b = scale; c = shape

b =1.76Dq-21.67………………………………………………………………………………4
(r^2 = 74.48 %; RMSE = 2.68; F = 8.76)
c =35.93-1.31H……………………………………………………………………………..5
(r^2 = 72.88 %; RMSE = 0.91; F = 8.06)
Where a, b, c, are Weibull parameters
Dq = Quadratic mean dbh
H = mean height
r^2 = Coefficient of determination
RMSE = Root Mean Square Error
F = Variance Ratio
* = Significant (p<0.05)

In this study, quadratic mean dbh appears to be the best predictor variable for the Weibull location and scale parameters while mean height appears to be a best predictor variable for the shape parameter. The coefficient of determination (R^2) for each of the equations were high with low standard error; the equations were significant at 5% level of significance; least values of mean residuals, standard deviation of residuals, sum of squares of residuals, coefficient of variation of residuals and high coefficient of determination. For instance, the r^2 for the equations are relatively higher than the works of Akinnagbe and Akindele (2003). Although they both observed mean dbh as a good predictor variable for the Weibull parameters in their studies of modeling stem diameter distribution in a permanent Sample Plot in Akure Forest Reserve, Nigeria.

CONCLUSION

The results of the research indicate the suitability of Weibull parameter in grading diameter distribution of trees. The Weibull distribution lends itself to some useful characterizations of stands. The models developed for predicting the Weibull from quadratic mean dbh were con-

Table 2. Correlation coefficients(r) Matrix of the Weibull parameter and stand growth attributes.

	a-location	*b*	*c*	*arith-mean*	*quard–mean*	*ln-arith*	*ln-quard*	*mean height*	*1/d*	*d2*	*squ d*	*No of stems/ha*
a-location	1											
B	0.993688	1										
C	-0.59939	-0.63145	1									
arith-mean	0.863139	0.849754	-0.13404	1								
quard–mean	0.870283	0.863014	-0.16056	0.998415	1							
ln-arith	0.849445	0.832572	-0.10326	0.999241	0.995656	1						
ln-quard	0.557632	0.495468	0.254994	0.827769	0.797071	0.848123	1					
mean height	0.283811	0.347603	-0.85371	-0.09737	-0.06162	-0.12939	-0.43615	1				
1/d	-0.70765	-0.7332	0.095341	-0.89962	-0.91316	-0.89277	-0.6756	-0.08923	1			
d2	0.256694	0.15769	0.060024	0.202307	0.160277	0.222678	0.426118	-0.51989	0.236749	1		
squ d	-0.28677	-0.37443	0.211384	-0.37588	-0.41638	-0.35395	-0.04051	-0.50192	0.727939	0.828083	1	
No of stems/ha	-0.484	-0.55514	0.211438	-0.60324	-0.63724	-0.58452	-0.27227	-0.4	0.879494	0.65669	0.965732	1

sistent and good prediction models since there were no significant differences in the observed and the predicted values of the parameters. The Weibull parameters obtained in this study can be used to generate the diameter class frequencies of various age group.

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