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Diameter Distribution for *Gmelina Arborea* (ROXB) Plantations in Ukpon River Forest Reserve, Cross River State, Nigeria

Ajayi, S.
Department of Forestry and Wildlife Resources Management
Cross River University of Technology,
P.M.B 102, Obubra
Cross River State, Nigeria
E-mail: samayodora@yahoo.com
Tel: +2348059456270; +2348038368014

Abstract

Weibull distribution-based models were developed and applied in the characterization of trees for sustainable production of Gmelina arborea in Ukpon River Forest Reserve, Cross River State, Nigeria. Forty-two sample plots of size 20m X 20m were randomly laid in the 19 - 33-year G. arborea age series and complete enumeration of diameter at breast height (DBH)) over bark was carried out. The growth data sets were then processed into size-class sets. A three–parameter Weibull distribution function (with α, β, and λ representing location, scale and shape parameters respectively) was fitted into the size-class data set using percentile estimates method. The equations obtained under diameter distribution revealed that α was *significantly related to S and N (r^2 = 0.53), common logarithm of β was significantly related to Age (r^2 = 0.81) while the common logarithm of λ was significantly related to reciprocal of A and BA (r^2 = 0.63) where A, N, BA and S are age, surviving number of trees per hectare, basal area per hectare and, site index respectively. Leptokurtic, Mesokurtic, and Platykurtic distributions characterize plantations of 20 – 24, 26 – 28 and 30- 32 years respectively.*

Key words: *Diameter at breat height, Gmelina arborea, sustainable production ,Ukpon River Forest Reserve, Weibull distribution function.*

Introduction

Gmelina arborea is a fast growing deciduous tree occurring naturally in India, Thailand, Cambodia and southern provinces of China but planted extensively in Nigeria, Sierra Leone and Malaysia. It is commonly planted as avenue trees, in gardens and also in villages along agricultural land, on village community lands and on wastelands. It is light demanding, tolerant of excessive drought but moderately frost hardy and has good capacity to recover in case of frost injury (Duke 1983). In Nigeria, large investments in *Gmelina arborea* plantations have been made particularly to provide raw materials for pulp and paper mills (Ajayi *et al*, 2004). The species is now being converted for timber production as a result of failure of the mills to utilize them (Adetogun & Omole, 2007). These plantations have outgrown the pulpwood production rotation of 8 years (Akachukwu 1981; Evans, 1992). Furthermore, silvicultural treatments have been limited; leaving stands untended. Natural and physical agencies such as diseases, wind and fire have superimposed their effects on the variations due to site, climate and management. Global concern for the sustainable management of these plantations has been expressed so as to achieve expected benefits (ITTO, 2001; 2003). Atte (1994) estimated about 10,000 ha of such *G. arborea* plantations in Cross River State. Plantation of this species at Edondon in Ukpon River Forest Reserve has age range of 19 – 33years. These plantations are currently managed for timber production. The fuel wood needs of surrounding communities are also considered in the management objective.

Growing stock inventory that describes a stand of trees by basic stand parameters comprising of age, basal area/hectare and stems/hectare is regarded as especially important for yield prediction purposes whenever the state of a stand is radically altered by natural causes (Shirly, 1983). The distribution of volume by size classes as well as the overall volume is needed as input for many forest utilization decisions (Okojie, 1981; Sokpon and Biaou, 2002). One widely applied management technique for even-aged stands is 'diameter distribution' modeling. In this approach, the number of trees per unit area in each diameter class is estimated through the use of mathematical functions, which provide relative frequency of trees by diameters. Mean tree heights are predicted for trees of given diameter in stands of specified characteristics (i.e. specified age, site index and stand density). Volume per diameter class is calculated by substituting the predicted mean tree heights and the diameter midpoints into tree volume or taper equations. Yield estimates are obtained by summing the volumes in the diameter classes of interest. Avery and Burkhart (1994) observed that, though only total stand values (e.g. age, site index, and number of trees per unit area) are needed as input, detailed stand distribution information is obtained as output. This enables alternative utilization options to be evaluated. Planning still relies on the use of growth models with mean diameter and mean height as principal and often exclusive descriptors of stand development. The distribution of diameters is a very informative parameter, which has been described as "the most potent single factor for depicting the properties of a stand of trees" (Gadow, 1983; Ajayi *et al*, 2006). It appears appropriate therefore to develop growth and yield prediction equation that will produce basic information on the structure and potential cuts from plantation forests.

The objective of this study is to develop and use Weibull distribution models to determine the diameter -class distribution of *G. arborea* plantation in Ukpon River Forest Reserve, Cross River State, Nigeria for rational allocation of wood for various end uses.

Methodology

Study area

The *G. arborea* plantations at Edondon are sited within Ukpon River Forest Reserve, Cross River State. The Ukpon River Forest Reserve has a total area of 12,950 hectares and managed by the Cross River State Forestry Commission. The plantation occupies about 3,757 hectares of the Forest Reserve. The Reserve falls along latitude 5.86^{o} N and longitude 8.46^{o} E (Forest Resource Study – Cross River State, 1990).

The mean annual rainfall ranges from 12.1mm in January to 378 mm in August. The rain is fairly distributed throughout the months of April to October. Mean annual temperature range from 27.6^o C in August to 33.1^o C in February. Strong winds usually accompany the onset of dry season, which is caused by hot and dry North East wind. The mean relative humidity range from 71% in February to 90% in August (Ajayi, 2005)

The Ukpon River Forest reserve lies within the lowland rainforest with fresh water swamp at the fringes of Ukpon River and Derived Savannah north of the reserve. The Reserve is heterogeneous in floristic composition. Recognizable tree species within the reserve include *Ricinodendron spp., Terminalia spp., Triplochiton scleroxylon , Sterculia spp., Pterygota spp., Khaya spp. Milicia excelsa, Garcinia spp., Chrisophyllum spp., Alstonia spp., Ceiba pentandra and Pterocarpus spp.*

The main rock types are granite gneisses and quart schist with gravels and occasional rock outcrops in some areas. The soil is derived from the Eze Aku formation of precambrian series. Edondon soils are classified as Cambisol of Acid Crystalline rock; Ogar, 1994).

The topography varies from undulating land on the south and southwestern parts of the plantation to rugged and hilly land on the North and Northeastern part of the Forest reserve. Many seasonal streams that flow northward and empty their waters into Ukpon River dissect the plantation. The access roads within the plantation are poorly developed and the existing routes are not maintained

The principal occupation of the communities around the Forest Reserve is farming. Major crops of interest are cassava, yams, cocoyams and plantains/banana. Other crops generally seen in common production are maize, eggplants, okra, pepper and melon. Majority of the inhabitants from the host communities depends on the *G. arborea* plantation for fuel-wood supply.

Data collection

Maps of the Forest Reserve were used to locate the boundaries of the plantation were located in the field. To allow for comparison of growth performance of one stand and the other, the age series were grouped into seven age classes – 20, 22, 24, 26, 28, 30 and 32 years and each treated as a compartment - (Okojie 1981). Forty-two sample plots of size 20 m X 20 m were laid in the 19 - 33-year *Gmelina arborea* age series (5, 5, 5, 6, 6, 7 and 8 plots for compartments A, B, C, D, E, F and G respectively). In each sample plot, measurements of diameter at breast height (dbh) over bark and height were made on all trees with dbh equal to or greater than 10 cm.

Development of Prediction equations for the Weibull parameters (α, β, and λ)

The Weibull is a 3-parameter distribution defined by the probability density function:

$$f(x) = \frac{\lambda}{\beta}\left(\frac{x - \alpha}{\beta}\right)^{\lambda - 1} \exp - \left[\left(\frac{x - \alpha}{\beta}\right)^{\lambda}\right] \quad \ldots\ (1)$$

The corresponding cumulative distribution function is given by:

$$F(x) = 1 - \exp - \left[\left(\frac{x - \alpha}{\beta}\right)^{\lambda}\right] \quad \ldots..\ (2)$$

for x, $\beta,\lambda > 0$ (in general, α can be positive, zero or negative, but for diameter distribution, α must be non-negative)

The parameter α is known as the location parameter, β as the scale parameter and λ as the shape parameter. The Weibull parameters α, β and λ completely specify a Weibull distribution which is used to generate the relative frequency of trees by dbh class for the given overall stand characteristics.

The data used for developing prediction equations for parameters of Weibull distribution include:

(a) Stand attributes for each plot

(i) Age of plantation (years)

(ii) Total number of trees per hectare (N/Ha)

(iii) Basal area per hectare (m^2/Ha)

(iv) Average height of dominant and co dominants/ Site Index.

(b) Estimates of Weibull parameters α, β, and λ per plot.

Estimation of stands attributes

i. Age (A): Plantation age was obtained from year of planting.

ii. Number of stems per hectare (N/Ha)

For each stand (compartment), this was estimated from all sample plots and the total area of the sample plots

$$N = \frac{\sum_{i=1}^{p} n_i}{\sum_{i=1}^{p} a_i} \quad \text{.....(3)}$$

where

N = number of stems per hectare (N/Ha)

n_i = Total count of trees in plot i

a_i = area of plot i (Ha)

p = number of plots in stand

iii. Basal Area per hectare

For each stand, basal area per hectare (m^2/ha) was estimated from the formula

$$\sum^{n} \sum^{m} g_{ij}$$

$j=1 \;\; i=1$

$$BA \quad = \quad \frac{\qquad\qquad}{\sum_{j=1}^{n} a_{jj}} \qquad \ldots..(4)$$

where,

BA	=	average basal area per/ ha (m^2)
g_{ij}	=	Basal area of individual trees i in plot j (m^2)
m	=	number of trees in each plot
n	=	number of plots in each stand
a_j	=	area of plot j (ha)

For individual trees, Basal area was determined using the formula:

$$g = \frac{\pi D^2}{4} \qquad \ldots..(5)$$

where,

g	=	basal area (m^2)
D	=	diameter at breast height (cm)
π	=	3.142

iv. Site Index per plot

Site Index at a given age and average height of Dominants and co-dominants was obtained from:

$$\text{Log } S = \text{Log } Hd + 6.776\,(A^{-1} - A_i^{-1})$$

$$\text{with} \quad \text{Log } Hd = 1.735 - 6.776\, A^{-1} \quad \text{(Ajayi, 2005)} \qquad \ldots..(6)$$

where,

S = Site index (m)

Hd = Average height of dominant and co-dominant trees

A = age of stand

A_i = Index age (25 years)

Estimates of Weibull parameters α, β, and λ per plot

Following the pattern of Dubey and Abernethy as reported by Clutter *et al* (1983), the 24^{th}, 63^{rd} and 93^{rd} percentiles of the dbh distribution per plot (arranged in order of magnitude were used to estimate the parameters of Weibull distribution per plot i.e

$$X_{24} = Y_{(0.24N)}$$
$$X_{63} = Y_{(0.63N)}$$
$$X_{93} = Y_{(0.93N)} \qquad \text{…..} (7)$$
$$X_{100p} = Y_{(1\,N)}$$

where,

X = dbh for the specified percentile (cm)

N = total number of trees per plot

Y_m = the *m*th value in the ordered arrangement of values dbh(cm)

The method stemmed from the fact that if three sample percentiles are known, each can be equated to the corresponding Weibull cumulative distribution function and the three equations solved iteratively for estimates of α, β, and λ for each plot.

If X_p represent the p-percentiles value in the sample, then from the definition of Weibull cumulative distribution function:

$$P = 1 - \exp\left(\frac{X_p - \alpha}{\beta}\right)^{\lambda} \qquad \text{…..} (8)$$

when the above expression is solved for X_p, it gives

$$X_p = \alpha + \beta \left[-\ln (1 - p)^{1/\lambda} \right] \quad \ldots\ldots (9)$$

Using the 24th, 63rd and 93^rd^ percentiles with equation 9 gives the simultaneous equation set

$$\begin{aligned} X_{24} &= \alpha + \beta \left[-\ln (0.76)^{1/\lambda} \right] \\ X_{93} &= \alpha + \beta \left[-\ln (0.07)^{1/\lambda} \right] \\ X_{63} &= \alpha + \beta \end{aligned}$$

which can be re-arranged as

$$\frac{X_{24} - X_{63}}{X_{93} - X_{63}} = \frac{-\ln (0.76)^{1/\lambda} - 1}{\left[-\ln (0.07)^{1/\lambda} \right] - 1} \quad \ldots\ldots (10)$$

$$\beta = \frac{X_{.24} - X_{.63}}{\left[-\ln (0.76)^{1/\lambda} \right] - 1} \quad \ldots\ldots (11)$$

and

$$\alpha = X_{.63} - \beta \quad \ldots\ldots (12)$$

α assumes zero where equation 12 gives negative value since dbh cannot be negative. Therefore, for any given set of values of $X_{.24}$, $X_{.63}$ and $X_{.93}$, equation 10 was solved iteratively to obtain an estimate of λ which was then used in equation 11 to produce β parameter estimate. Once β was determined equation 12 was solved to estimate the origin parameter α.

Model formulation for Weibull parameters

The plot-by-plot percentile estimates of α, β, and λ and stand attributes were tabulated for the 42 plots in the seven compartments. This formed the data set for developing regression equation for predicting Weibull parameters α, β and λ for *G. arborea* plantations at Edondon.

The regressions (stepwise) were performed using the enhanced version of SPSS on a personal computer. The multiple regression models listed for screening were of the form:

For α (i) $\alpha = b_0 + b_1 \ln S + b_2 \log N$ ….. (13)

(ii) $\alpha = b_0 + b_1 S + b_2 N$ ….. (14)

For β, (i) $\log \beta = b_0 + b_1 A$ ….. (15)

(ii) $\log \beta = b_0 + b_1 \ln A$ ….. (16)

(iii) $\beta = b_0 + b_1 \ln N$ ….. (17)

For λ, (i) $\log\lambda = b_0 + b_1 A\text{-}1 + b_2 BA$ ….. (18)

(ii) $\log\lambda = b_0 + b_1 \log BA = b_2 \ln A$ ….. (19)

(iii) $\lambda = b_0 + b_1 \log BA + b_2 \ln A$ ….. (20)

where,

A = age of stand (years)

N = number of trees per hectare (N/Ha)

S = Site Index

BA = Basal Area per Hectare (m^3/Ha)

α, β and λ = Weibull parameters

Criteria for model selection

The selection of the best Weibull parameter models was based on the same criteria spelt out for Individual tree volume i.e

- Significant variance ratio (F) at 5% probability level
- A goodness of fit with high coefficient of determination (R^2).

- Least root mean square error (RMSE).
- Least Furnival Index

Adequacy of model

The normal probability plot was used for checking the adequacy of fit for the selected models.

Calculation of diameter-class frequencies from Weibull distribution

Weibull parameters α, β and λ were predicted for each compartment using stand attributes (Age, number of trees per hectare, basal area per hectare and site index). For a compartment of known age, number of trees/ha, basal area per hectare and site index, and Weibull distribution parameters α, β and λ determined, the probability of the population within a given diameter class was determined by fitting the Weibull parameter values into:

$$P_i\ (L_i < X < U_i) = \exp\left(-\left(\frac{L_i - \alpha}{\beta}\right)^{\lambda}\right) - \exp\left(-\left(\frac{U_i - \alpha}{\beta}\right)^{\lambda}\right) \quad \ldots\ldots (21)$$

where,

P_i	=	probability of trees in class i
L_i	=	lower limit of class i
U_i	=	upper limit of class i
X	=	random dbh (cm)
α, β and λ	=	known Weibull parameters

Results and discussion

Weibull parameters

Table I presents the regression constants and coefficients, R^2, RMSE, F-ratio and FI for Weibull parameters α, β and λ.

There are two models for the origin parameter α (I and II). Model II with 52.7% coefficient of determination (R^2) and Furnival Index of 4.7044 was selected for predicting parameter α in *G. arborea* plantations at Edondon. Model I is judged suitable for predicting parameter α since the relevant statistics are closely related to those of model II. Site and number of trees per hectare were very relevant stand characteristics for predicting the origin parameter in *G. arborea* plantations at Edondon (Okojie, 1981).

The regression of logarithmic transformation of parameter β against age gave a more appropriate model for predicting scale parameter as can be seen in model III on table I. About 81% of the variation in the dependent variable (Log β) is explained by age (A). Age is the single most relevant variable for the prediction of scale parameter in *G. arborea* plantations at Edondon. Models IV and V are also suitable for predicting scale parameter β.

For the shape parameter λ, model VI was selected. Age and Basal area explained about 63% variation in the logarithm of λ, so they are very relevant to the prediction of shape parameter in *G. arborea* plantations at Edondon. The untransformed dependent variable of model VIII from table I shows R^2 of 65%. In spite of the higher multiple coefficient of determination, the model is characterized by higher RMSE and FI of 0.3993 each. That notwithstanding, models VII and VIII are considered suitable. The normal probability plots for the α, β and λ parameters presented in Figures Ia – c follow the usual straight line pattern indicating that they are adequate for predicting Weibull parameters in *G. arborea* plantations at Edondon (Armitage and Berry, 1987).

Table II shows the Weibull parameter estimates derived from the three models selected from Table I.

The table indicates that origin parameter decreased with age (14.6738 cm at age 20 years to 0.8233 cm at age 32years). The scale and shape parameters increased with age.

Prediction by diameter classes

Figure II shows high peakedness (leptokurtic curve) and slightly positive skewness for diameter distributions in ages 20 to 26 years and almost zeros skewness and mesokurticity for ages 28 – 30 and symmetry and platykurticity for age 32 years. High peakedness and positive skewness means that considerable numbers of trees are concentrated in the lower diameter classes while zero skewness and mesokurticity shows a normal distribution of the values of observations around the mean. Symmetry and platykurticity suggest flat-topped distribution (Gadow, 1983).

The distributions of the age series are unimodal i.e they have single peaked. The distributions for 20 and 22 year's plantations have their peaks of 480 trees/hectare and 416 trees/hectare respectively in the 20 – 30 cm diameter class. The 30 – 40 cm dbh class contains peaks of 340 trees/hectare, 258 trees /hectare and 219 trees /hectare for distributions in ages 24, 26 and 28 years respectively. The distribution peaks of 185-trees/hectare and 145-rees/hectare for 30 and 32-year old plantations fall in the 40 - 50cm and 50 – 60 cm dbh classes respectively. The management objective of timber production (>80 cm dbh) will mean allowing the plantation for some years so that more of pole size trees (40 – 80 cm) can grow to timber size while the fuel wood need of communities around the plantation can be taken care of by trees in the lower diameter classes (< 40cm).

Conclusions

The Weibull function is very suitable for fitting continuous diameter distributions because of its flexibility in depicting positive as well as negative skewness. The study reveals that a high proportion of trees in *G. arborea* plantations in Ukpon River Forest reserve are mostly of pole size with very few trees of timber size scattered in the older plantations of 30 - 32 years. Intensive Forest management is recommended if the main management objective of timber production is to be realized. The application of continuous distribution functions is an elegant solution for describing the structure of forest stands. A structure model that is based on continuous distribution function remains compact and easy to use. All the essential yield elements required in forestry planning can be derived if the structure of the stand is known. This is an important tool in planning harvest schedules that rely on linear programming, for example.

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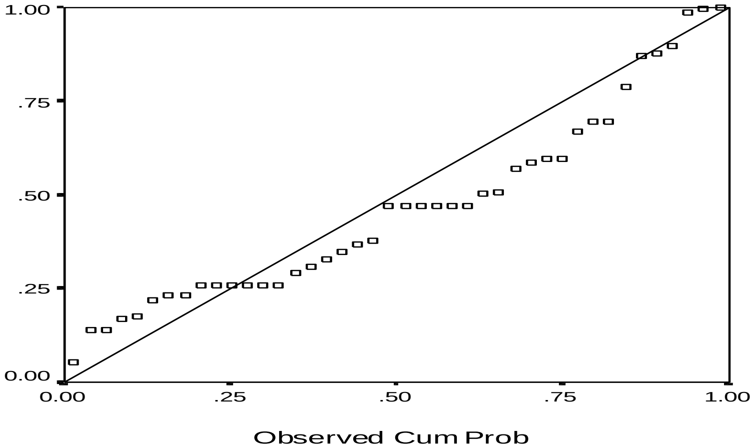
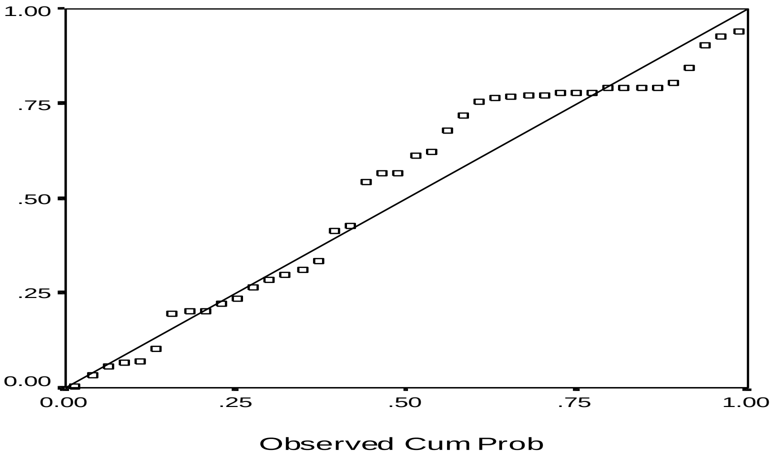
Table I: Regression Analysis Result of Weibull Parameters (α, β and λ) for *G.Arborea* Plantations at Edondon

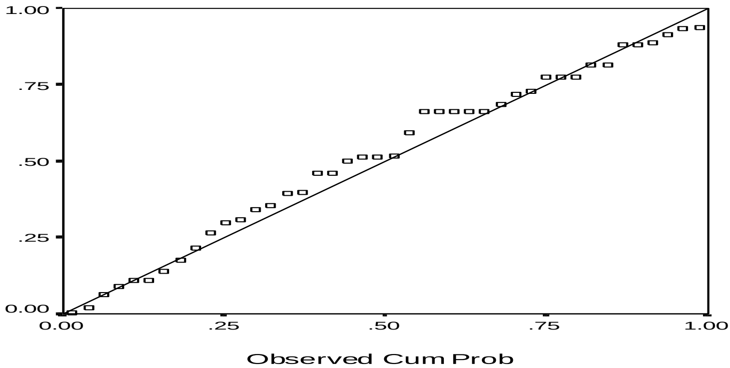
MO-DEL	DEP. VAR.	REG. CONST.	REGRESSION COEFFICIENTS	R^2 (%)	RMSE	F-RATIO	FI	REMARK
I	α	-263.926	22.048 Ln S + 66.607 Log N	52.5	4.7146	21.553	4.7146	SUITABLE
II	α	-42.090	.670 S + 3.259-02 N	52.7	4.7044	21.731	4.7044	SELECTED
III	Log β	..307	4.581 E - 02 A	81.1	.09142	172.121	3.0913	SELECTED
IV	Log β	-2.332	1.180 Ln A	80.9	.09201	169.412	3.1113	SUITABLE
V	β	635.798	- 90.766 Ln N	80.1	7.5534	161.313	7.5534	SUITABLE
VI	Log λ	2.041	- 27.769A^{-1} - 5.37E-03 BA	63.2	.0779	33.467	.1877	SELECTED
VII	Log λ	-.632	-1.195 Log BA + 1.054 Ln A	62.9	.0781	33.125	.1883	SUITABLE
VIII	λ	-2.683	- 6.642 Log Ba + 5. 717 Ln A	65.0	.3993	36.214	.3993	SUITABLE



(a) α



(b) *Log* β)



(c) *Log λ)*

Figure I a - c: Normal probability plot for Weibull parameters α , Log β, and Log λ)

Table II: **Weibull Parameter Estimate for *G. Arborea* Plantations at Edondon**

S/N	Stand Attributes				Weibull Parameters		
	Age A (Yrs)	Number of stems N N/ha	Basal Area BA (M^2/ha	Site Index S (M)	α	β	λ
1	20	1125	85.97	30	14.6738	16.7186	1.5520
2	22	1070	90.47	29	12.2113	20.6452	1.9631
3	24	110	94.42	28	9.9859	29.4941	2.3819
4	26	929	117.85	29	7.6161	31.4148	2.1183
5	28	850	119.66	29	5.0145	39.8759	2.5508
6	30	786	121.20	28	2.9557	48.0065	2.9142
7	32	700	124.37	30	0.8230	59.2818	3.2007

$$\alpha = -42.090 + .670\ S + 3.259E\text{-}02N$$

$$\text{Log } \beta = .307 + 4.581E\text{-}02\ A$$

$$\text{Log } \lambda = 2.041 - 27.769\ A^{-1} - 5.37E\text{-}03\ BA$$

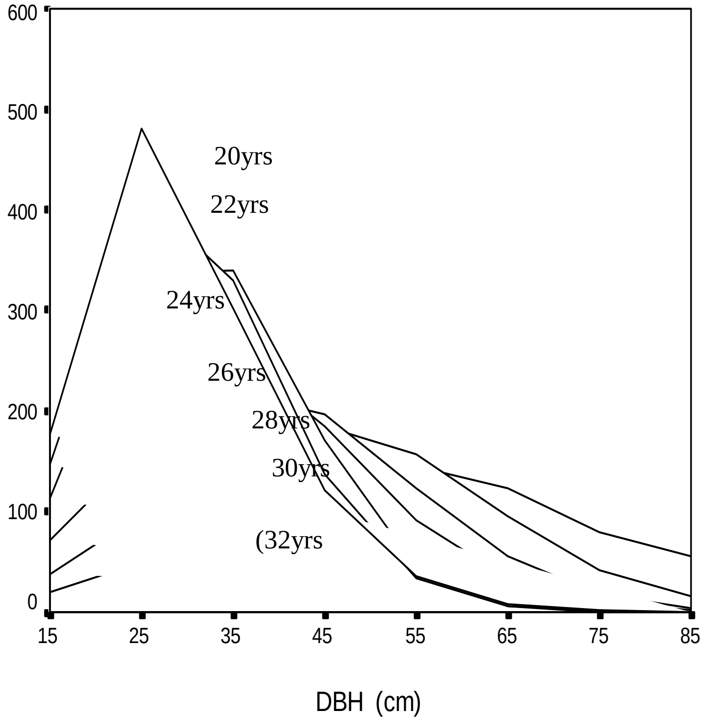


Figure II: Diameter distribution for *G. arborea* Plantations at Edondon (N/Ha)