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Dr. Joseph Oludayo ADEGBEHIN

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GROWTH PREDICTION IN SOME PLANTATIONS OF EXOTIC
TREE SPECIES IN THE NORTHERN GUINEA AND DERIVED
SAVANNA ZONES OF NIGERIA

BY

JOSEPH OLUWAYEMI ADEGBEHIN

B.Sc. (For.) MAKERERE, M.Sc. (For.) DAR ES SALAAM

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ABSTRACT

Growth studies which include diameter distribution using the Weibull function, development of stand volume models, and construction of provisional top height-age and total volume production-age curves for the average site class were carried out in plantations of Eucalyptus cloeziana, E. tereticornis and Pinus caribaea. The study locations were Kabama (Zaria) and Afaka (both typical of Northern Guinea savanna zone of Nigeria), Nimbia (Derived savanna zone) and Miango, Vom and Ta-Hoss (on the Jos Plateau). E. cloeziana represented only at Afaka had 4 experimental sample plots with age range of 4.2 - 15.5 years. E. tereticornis represented at Kabama and Afaka had 6 sample plots with ages from 3.7 - 15.5 while P. caribaea represented in all the study locations except Zaria had 43 plots with ages between 4.7 - 29 years.

In fitting the Weibull distribution to the individual diameter plot data, WWINGO, the most suitable Weibull (program) subroutine for determining

the Weibull parameters in the stands, was capable of describing the diameter distribution in the plots as from the minimum age of 4 years for E. cloeziana and 6 years each for E. tereticornis and P. caribaea. On testing the Weibull parameter predictive models constructed (based on stand attributes and site factors) in new stands, while those of E. cloeziana and E. tereticornis gave good predictions as from the respective minimum age limits stated above, those of P. caribaea did not give reliable predictions until the age of 10 years.

With reference to the stand volume model developed for each species, that of E. cloeziana gave the best prediction with the root mean square error (RMSE) of $2.25 \text{ m}^3/\text{ha}$, followed by that of E. tereticornis with RMSE of $4.7 \text{ m}^3/\text{ha}$ and that of P. caribaea with RMSE of $10.1 \text{ m}^3/\text{ha}$. The models predicted well within the range of field data when tested in new stands.

Out of the three functions used in fitting the provisional top height-age (site index) curve for the average site class for each species, the

Gompertz model, in most cases, gave better fittings than the Logistic while the polynomial function was the poorest. Based on the best-fit model for each species and some other criteria, a provisional average site class was defined as top height of 27.4 m at a reference age of 13 years for E. cloeziana, 24.8 m at the age of 15 years for E. tereticornis and 23.4 m at age 20 for P. caribaea.

The Gompertz model was also more reliable than the Logistic in fitting the provisional average total volume production-age curve for each of the species. A maximum total volume production of about 240 m³/ha at age 13.4 years, 286 m³/ha at age 19.4 years and 726 m³/ha at age 30 could be obtained for E. cloeziana, E. tereticornis and P. caribaea, respectively, on an average site.

The applications of the Weibull parameter predictive models in forest management, and the expected optimum rotation ages for the species in view of the growth figures obtained from the other growth models were discussed.

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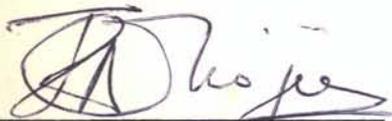
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Certification

We certify that this work was carried out by Mr. Joseph Oluwayemi Adegbehin of Savanna Forestry Research Station, Samaru, Zaria, under our supervision.



MAJOR SUPERVISOR

Dr. J. A. Okojie
B.Sc.(For.)(Ibadan)
M.F.(Yale), Ph.D.(Ibadan)

Snr. Lecturer in Dept. of
Forest Resources
Management,
University of Ibadan



SUPERVISOR

Dr. S. Nokoe
B.Sc.(For.)(Ibadan)
M.F., Ph.D.(Brit. Col.)
Biometrician, Chief
Research Officer(F.R.I.N)
and Part-time Lecturer at
Dept. of Forest Resources
Management,
University of Ibadan

TABLE OF CONTENTS

	Page
Abstract	ii
Acknowledgements	v
Certification	viii
List of Figures	xvii
List of Tables	xxii
CHAPTER 1 INTRODUCTION	1
1.1 Savanna zones of Nigeria	1
1.2 Justification	3
1.2.1 Importance of growth and yield data	7
1.2.2 Previous studies on growth and yield of some tropical pines and some eucalypts	12

	Page
1.3 Objectives	14
1.4 Scope of study	15
CHAPTER 2 GROWTH AND YIELD MODELLING IN FORESTRY	16
2.1 General	16
2.2 Statistical description of forest data.	17
2.2.1 Unimodal distributions and skewness of diameter and height in even-aged stand.	20
2.2.2 Distribution models in forestry.	23
2.2.2.1 Common probability functions for growth and yield studies	24
2.2.2.2 Growth and yield empirical prediction models	33
2.2.3 Stand growth with age	41

	Page
2.3 Growth and yield simulation models	45
2.3.1 Classification criteria for simulation models	46
2.3.2 Types of forest stand models	50
2.3.2.1 Single tree models	51
2.3.2.2 Whole stand/ distance independent models	61
CHAPTER 3 THE STUDY AREA AND MANAGEMENT HISTORY	70
3.1 Study locations	70
3.2 Establishment of plantations and previous management practices	70
CHAPTER 4 BASIC DATA AND DATA SCREENING PROCEDURES	76
4.1 Data source and sample plot records.	76

4.2	Field data.	77
4.2.1	Plot sizes, distribution and espacement.	78
4.2.2	Age range of trees covered by data collection.	78
4.2.3	Observed stand attributes and site factors.	80
4.2.4	Range of stand data and type of statistics computed for each plot.	83
4.3	Data screening	86
4.4	Data for prediction models	91
4.4.1	Data for Weibull distribution.	91
4.4.2	Data for top height-age curves.	92
4.4.3	Data for volume prediction	93
CHAPTER 5	MODEL SELECTION AND FITTING PROCEDURES	94
5.1	Flow-chart for model selection and fitting procedures	94
5.2	Procedure for diameter prediction	96
5.2.1	The Weibull program	100

	Page
5.2.1.1 Data input programs.	106
5.2.1.2 Determination of the Weibull parameters.	107
5.2.1.3 Determination of the parameters for gamma distribution.	114
5.2.1.4 Preliminary analyses for the Weibull distribution trial fittings.	116
5.2.1.5 Procedure for Weibull parameter predictive models.	120
5.3 Model fittings for top height-age data.	125
5.4 Procedure for volume prediction	129
5.4.1 Procedure for stand volume models.	131
5.4.2 Model fittings for total volume-age data.	131

	Page
CHAPTER 6 RESULTS AND DISCUSSION	140
6.1 Results of preliminary analyses for the Weibull distribution.	140
6.1.1 Comparisons of the actual and predicted cumulative diameter distributions.	143
6.1.2 Comparisons of the fittings from WWINGO subroutine and gamma distribution.	150
6.2 Results of the main analyses for the Weibull distribution.	152
6.2.1 Weibull distribution fitted to individual plot data and relationship between the estimated parameters and age.	152
6.2.2 Weibull distribution fitted to pooled diameter data of each species.	154

6.2.3	Correlations of the Weibull parameters with the other stand attributes and the site factors.	155
6.2.4	Weibull parameter predictive models.	164
6.2.4.1	Weibull parameter models for the individual species.	169
6.2.4.2	Testing of models in new stands.	178
6.2.4.3	Discussion.	182
6.3	Models for top height-age curves.	188
6.3.1	Provisional site index curves.	194
6.4	Volume prediction	195
6.4.1	Inter-correlations of stand variables.	196
6.4.2	Stand volume models.	202
6.4.2.1	Testing of models in new stands.	208

	Page
6.4.3 Models for total volume-age curves.	213
6.4.3.1 C.A.I and M.A.I for the average site .	221
6.5 General discussion.	225
CHAPTER 7 CONCLUSIONS AND SUGGESTIONS	235
7.1 The Weibull parameter models.	235
7.2 The volume models and growth and yield data.	238
REFERENCES.	241
APPENDICES.	275

LIST OF FIGURES

FIGURE		PAGE
2.2	Kurtosis: the degree of peakedness of frequency distribution curves.	22
2.2.1	Shapes of diameter frequency distribution curves with increasing age in an unmanaged pure stand.	22
2.2.2.1a	Gamma distribution.	28
2.2.2.1b	Beta distribution.	28
2.2.2.1c	Uniform density distribution.	29
2.2.2.1d	Weibull distribution and values of 'b' and 'c' for all-aged forests.	32
2.2.3a	Relationship between height and diameter with increasing age.	42

LIST OF FIGURES (CONTD.)

FIGURE		PAGE
2.2.3b	Relationship between stocking and age in a managed even-aged forest.	43
2.2.3c	Relationship between top height and age in a forest stand.	44
2.2.3d	Relationship between total volume production and age.	45
2.3.2	Basic forest stand modelling philosophies.	50
3.1	Map of vegetation zones of Nigeria and location of study areas.	71
5.1	Flow chart for model selection and fitting procedures.	95

LIST OF FIGURES (CONTD.)

FIGURE		PAGE
5.2	Plotting of skewness squared against kurtosis of plot data on $B_1 - B_2$ space graph.	98
5.2.1(a)	Cumulative density curve of the 3-way parameter Weibull distribution.	101
5.2.1(b)	Changes in shape of the modified Weibull increment curves at varying values of 'c' and 'b'.	105
5.3(a)	Fitting of the average site index curve for <u>E. cloeziana</u> .	126
5.3(b)	Fitting of the average site index curve for <u>E. tereticornis</u> .	127
5.3(c)	Fitting of the average site index curve for <u>P. caribaea</u> .	128

LIST OF FIGURES (CONTD.)

FIGURE		PAGE
5.4.2(a)	Fitting of the average total volume production/age curve for <u>E. cloeziana</u> .	133
5.4.2(b)	Fitting of the average total volume production/age curve for <u>E. tereticornis</u> .	134
5.4.2.1	Fitting of the average total volume production/age curve for <u>P. caribaea</u> .	139
6.1.1(a-e)	Comparisons of the predicted c.f.d from DAGOS and WWINGO with the c.f.d of the actual data - <u>E. tereticornis</u> at Kabama.	146

LIST OF FIGURES (CONTD.)

FIGURE		PAGE
6.1.1(f-i)	Comparisons of the predicted c.f.d from DAGOS and WWINGO with the c.f.d of the actual data - <u>P. caribaea</u> at Afaka.	148
6.1.2	Comparisons of the c.f.d from the WWINGO with the c.f.d from Gamma, DAGOSTINO and the actual data - <u>E. cloeziana</u> at Afaka.	151
6.4.2	Comparisons of the observed and predicted standing volumes for <u>E. cloeziana</u> , <u>E. tereticornis</u> and <u>P. caribaea</u> .	206
6.5	Comparisons of the average total volume production/age curves (based on the Gompertz function) for <u>E. cloeziana</u> , <u>E. tereticornis</u> and <u>P. caribaea</u> .	227

LIST OF TABLES

TABLE		PAGE
1.1	Price list (amount in naira) for eucalypt poles and cords in some Northern States of Nigeria in 1978.	6
3.1	Site characteristics of study areas.	72
4.2.1	Distribution of sample plots by location and species.	79
4.2.2	Classification of sample plot data by age classes and species.	80
4.2.4(a)	Summary of the range of stand data.	84
4.2.4(b)	The type of usual statistics computed for each plot.	85
4.3(a)	Data summary for <u>E. cloeziana</u> showing the values of skewness and kurtosis at various ages and stocking at Afaka.	88

LIST OF TABLES (CONTD).

TABLE		PAGE
4.3(b)	Data summary for <u>E. tereticornis</u> showing the values of skewness and kurtosis at various ages and stocking.	89
4.3(c)	Data summary for some of the <u>P. caribaea</u> plots showing the values of skewness and kurtosis at various ages and stocking.	90
5.4.2	Correlations of the total volume production with age and top height for the three species.	132
5.4.2.1	Estimation of the quadratic mean diameter and total volume production from an assumed unthinned stand of <u>P. caribaea</u> at an average site:	136

LIST OF TABLES (CONTD).

TABLE		PAGE
6.1	Comparisons of the results from different subroutines of the multi-Weibull programs.	141
6.1.1(a)	Results of K-S test between the c.f.d of the actual data and the predicted c.f.d. with different Weibull subroutines - Data from <u>E. tereticornis</u> at Kabama.	149
6.1.1(b)	Results of K-S test between the c.f.d of the actual data and the predicted c.f.d with the different Weibull subroutines - Data from <u>P. caribaea</u> stand at Afaka.	149

LIST OF TABLES (CONTD).

TABLE		PAGE
6.2.1	Correlations of the Weibull parameters with age for <u>E. cloeziana</u> , <u>E. tereticornis</u> and <u>P. caribaea</u> .	154
6.2.3(a)	Correlations of the Weibull parameters with stand attributes for <u>E. cloeziana</u> .	159
6.2.3(b)	Correlations of the Weibull parameters with stand attributes and site factors for <u>E. tereticornis</u> .	160
6.2.3(c)	Correlations of the Weibull parameters with stand attributes and site factors for <u>P. caribaea</u> .	161
6.2.3(d)	Inter-correlations of the Weibull parameters for <u>E. cloeziana</u> .	162

LIST OF TABLES (CONTD).

TABLE		PAGE
6.2.3(e)	Inter-correlations of the Weibull parameters of <u>E. tereticornis</u> .	162
6.2.3(f)	Inter-correlations of the Weibull parameters for <u>P. caribaea</u> .	163
6.2.4.1(a)	Observed and predicted Weibull parameters for <u>E. cloeziana</u> .	171
6.2.4.1(b)	Observed and predicted Weibull parameters for <u>E. tereticornis</u> .	173
6.2.4.1(c)	Comparisons of the residual mean square errors for the predicted Weibull parameters for the three species.	173

LIST OF TABLES (CONTD).

TABLE	PAGE
6.2.4.1(d) Observed and predicted Weibull parameters for <u>P. caribaea</u> .	176
6.3(a) Gompertz parameters for top height-age curves for <u>E. cloeziana</u> , <u>E. tereticornis</u> and <u>P. caribaea</u> .	190
6.3(b) Logistic parameters for top height-age curves for <u>E. cloeziana</u> , <u>E. tereticornis</u> and <u>P. caribaea</u> .	190
6.3(c) Predicted top heights for <u>E. cloeziana</u> with Gompertz, Logistic and polynomial functions.	192

LIST OF TABLES (CONTD).

TABLE		PAGE
6.3(d)	Predicted top heights for <u>E. tereticornis</u> using the Gompertz, Logistic and the polynomial functions.	192
6.3(e)	Predicted top heights for <u>P. caribaea</u> based on the Gompertz, Logistic and the polynomial functions.	193
6.4.1(a)	Intercorrelations of the stand variables for <u>E. cloeziana</u> .	199
6.4.1(b)	Intercorrelations of the stand variables for <u>E. tereticornis</u> .	200
6.4.1(c)	Intercorrelations of the stand variables for <u>P. caribaea</u> .	201

LIST OF TABLES (CONTD).

TABLE	PAGE
6.4.2.1(a) Observed and predicted standing volumes for <u>E. cloeziana</u> based on data from new stands.	211
6.4.2.1(b) Observed and predicted standing volumes for <u>E. tereticornis</u> using data from new stands.	211
6.4.2.1(c) Observed and predicted standing volumes for <u>P. caribaea</u> using data from new stands.	212
6.4.3(a) Gompertz parameters for volume-age curve for each of the three species.	214
6.4.3(b) Logistic parameters for volume-age curve for each of the three species.	215

LIST OF TABLES (CONTD).

TABLE	PAGE
6.4.3(c) Gompertz and Logistic parameters for volume-age curves for an assumed unthinned <u>P. caribaea</u> stand.	215
6.4.3(d) Predicted total volume production for <u>E. cloeziana</u> with the Gompertz and the Logistic functions.	217
6.4.3(e) Predicted total volume production for <u>E. tereticornis</u> with the Gompertz and Logistic functions.	218
6.4.3(f) Predicted total volume production for <u>P. caribaea</u> (original data) based on the Gompertz and Logistic functions.	219

LIST OF TABLES (CONTD).

TABLE	PAGE
6.4.3(g) Predicted total volume production for <u>P. caribaea</u> (from the assumed unthinned stand) based on the Gompertz and the Logistic functions.	220
6.4.3.1 Ages at which C.A.I and M.A.I reach the peak and their associated volumes for the average site .	222
6.5(a) Provisional site index classes for <u>P. caribaea</u> at a reference age of 20 years.	232
6.5(b) Comparisons of "height class" figures for <u>P. caribaea</u> at Trinidad and Tobago with the provisional site class figures.	233

CHAPTER 1

INTRODUCTION

1.1 Savanna zones of Nigeria

The Savanna region covers the northern four-fifths (about 800,000 Km²) of Nigeria and supports about three quarters of the over 80 million people. According to the classification by Keay (1959), four major ecological zones are recognized and designated Southern Guinea, Northern Guinea, Sudan and Sahel savannas. In addition to these four true savanna zones, a transition zone termed "derived savanna" is also distinguished and this refers to areas of savanna dotted with patches of the original rain-forests. The so-called "derived savanna" areas are believed to have been covered by rain-forests previously, but the effect of human activities (such as farming, grazing and so on) have given them their present outlook.

A detailed description of the vegetation types and soil in each zone have been given by Keay (loc.

cit.). The Northern Guinea zone, where most of this research was concentrated, covers only about 25 per cent of the 800,000 Km² land area, but supports the growth of more exotic tree species than any other zone of the savanna. There is the possibility that this zone could supply wood to some other parts of the North in future.

The natural vegetation in most of the savanna areas has been adversely affected by past cultivation, fire and grazing leading to the reduction or removal of forest cover and subsequently the enhancement of wind/water erosion. As a result of this, the residual natural vegetation is incapable of meeting, both in quantity and quality, the rapidly increasing wood requirements for sawnwood, fuelwood, telephone and transmission poles as well as materials for pulp and paper production.

Apart from human interferences, the growth rate of the indigenous tree species in reserved areas is not encouraging. Kemp (1963) estimated the yield from the Northern Guinea savanna woodland as 21.7 m³/ha over a period of 50 years. Thulin (1966) had however estimated that, in 1965,

the former Northern Nigeria which occupied the bulk of the savanna areas of Nigeria consumed 23.8 million m³ of wood annually. He anticipated this consumption would increase by 7 or 24 per cent for low or high rate of population growth by 1980 respectively; for the year 2000, increases of 20 and 75 per cent for low and high population growth respectively were estimated. Actually, the future wood deficit in the savanna region was recognised as early as 1920 by the Nigerian Forest Authority and the trial of exotics together with planting trials of selected indigenous species were commenced in some of the savanna areas (Kennedy, 1932). The slow growth rates of the planted indigenous species compared with the exotics led to the programme of intensive species trials that commenced in 1959.

1.2 Justification

The importance of growth and yield data, in projecting wood supplies for the country and in planning the optimum uses of factors of production,

both in the forestry sector and in the wood-using industries, cannot be over-emphasised. Generally, only limited amount of research work has been carried out in this field with regard to the exotic tree species in the Northern parts of the country. Hence only preliminary information on the growth rates of these species (mostly pines and eucalypts) is available (Kemp, 1970; Iyamabo et al., 1972; Anon, 1974; Adegbehin, 1980, 1981 and 1983).

The species investigated in the study include Pinus caribaea, Eucalyptus tereticornis and E. cloeziana. P. caribaea and E. tereticornis have passed through the various stages of species trials and are now being planted on large scale in plantations. Although P. caribaea may not provide high quality wood as the mahoganies, it has the advantage of shorter rotation of 20 - 35 years for sawn-wood production (Marsh, 1967 and Crowe, 1967). One other promising species of pine not covered in this investigation is P. oocarpa. Plantations of this are generally younger than those of P. caribaea and, of course, the species is less fire resistant.

Considering that P. oocarpa has a comparable growth rate with P. caribaea (Adegbehin, 1981), the results obtained from the latter can give an insight of what to expect from P. oocarpa. The inclusion of E. tereticornis in the study is very essential because it is easily adapted to various parts of the Northern Guinea savanna and is a good pole, post and fuelwood material on a rotation of 5 - 12 years and can be managed for sawwood on longer rotation. Table 1.1 shows that products from eucalypts fetch attractive revenues in some parts of the Northern States. E. cloeziana, though soil selective and with low survival percentages in many areas has been included in the study because, in some areas where the species got well established at Afaka, it performed better than all other species of eucalypts of its age in terms of volume production. Moreover, its growth rate compares favourably with that of E. camaldulensis which was not investigated in this study because the plantations were very young.

Table 1.1 Price list (amount in naira) for eucalypt poles and cords in some Northern States of Nigeria in 1978*

Pole size, Diameter (cm) at stump height**	Kaduna State	Plateau State	Kano State ⁽²⁾	Bauchi State ⁽²⁾
7 - 10	1.00			
10 - 13	2.75			
13 - 16	4.00			
16 - 19	6.00			
19 - 22	8.00			
22 - 25	10.00			
10 - 19		1.60		
19 - 29		2.50		
29 - 39		5.00		
Price per cord ⁽¹⁾	8.00	2.700	14.00	10.00

* Source: Adegbehin (1978)

** Stump height is 15 cm above the ground level

(1) A cord of wood is 3.62 m³ stacked volume

(2) In Kano and Bauchi States, eucalypts were not sold by tree sizes, but in cords.

Both pines and eucalypts can play important roles in the supply of raw materials to pulp and paper industries as practised in Kenya (Konuche, personal communication¹). This will in turn save the country some foreign exchange which could have

1) Mr. A. Konuche, a silviculturist, is responsible for raising plantations of pines and eucalypts for the Pan-African pulp and paper mill at Webuye, Kenya.

been used to import paper products. Moreover, Eucalyptus oils which are still being imported can be extracted from eucalypt leaves and bark which are usually residues after harvesting. The potentialities of extracting oils from eucalypts planted in Northern States of Nigeria has been discussed (Akinloye and Adegbehin, 1981).

1.2.1 Importance of growth and yield data.

Growth and yield data are very important in forest management for the following reasons.

(a) Production planning.

Where several species of given (or the same) end uses are planted in a certain locality, it will be more profitable to establish a larger hectarage of that species with the highest growth rate.

Effective forest management involves the use of treatment regimes such as spacing and thinning to control the growing stock. Marsh's (1967) report of the correlated curve trend (C.C.T.) experiments on stocking in stands of pines at varying ages have

confirmed this. Thinning regime can be varied in favour of products of high market value or of immediate use to the community. If poles of a certain diameter class are in high demand, reducing the growing stock to a certain number per hectare may lead to a reduction in the maturity period. By varying espacement and thinning regime, it is also possible to achieve the optimum volume out-put for different products such as fuelwood, pulpwood, poles, sawnwood etc.

(b) Valuation of stands

If the growth rate of a species has been determined in a certain area, or a growth model has been developed for the species in that locality, it then becomes possible to estimate the standing volume of the species at any age. Volume tables, yield tables and site index curves, when available, are very useful tools in this type of exercise. The forest owner using the current prices of the forest products can then determine the money value of his forest stands and assess by how much the value of his asset has increased over the previous years.

(c) Stand projection for efficient management

There are several recent changes in forestry which require stand projections for management decisions. First, integrated utilization is commonly practised and the tree size, particularly diameter, is the usual limiting factor for utilization for a specific product. Some computer models have been developed in line with this objective. Among these are the FORTRAN computer programs called YIELD and THINI developed by Myers and Godsey (1968). The programs produce a set of yield tables for managed even-aged timber stands. Information in the yield tables includes the periods of intermediate cuts, mean d.b.h. of thinning, number of trees to be thinned per hectare, basal area cut, and mean d.b.h., basal areas and number of main crop trees at varying ages. The PONYLD program later developed by Myers (1971) is another projection aid. PONYLD can be modified in many ways to show the results of various thinning alternatives.

(d) Rotation age

The rotation age of a forest is often very difficult to determine as it may be dependent on several factors such as the urgent need for money by the forest owner, anticipation that prices of forest products will rise, uses of the products and so on. The best criterion for determining rotation seems to be the economic optimum production point rather than the point of maximum mean annual increment (M.M.A.I.). However, this economic optimum production point can only be calculated based on growth figures. The net discounted revenue (N.D.R) method (Johnston et al., 1967) may be of practical application in this regard.

(e) Sustained yield

The concept of sustained yield when implemented keeps the standing volume of the growing stock constant and regulates the rate of exploitation in the forest. This means that the volume cut from the forest over a certain period must not

exceed the increment over the same period. Therefore, a thorough knowledge of the growth rate of the tree species at any particular time is desirable.

(f) Establishment of wood and wood-based industries

It is often very expensive to transport logs over long distances. Therefore in the establishment of wood and wood-based industries it is ideal to have the industries located near areas where the available figures of wood production from the forests or the potential yield from the proposed plantations can sustain the industries. In many developing countries where this fact has been neglected, either for political or other reasons, this had often led to high cost of production or sometimes closing down of such industries. Moreover, the purchase of logging equipment depends on yield data from the forest if logging operation is to be maintained at minimum cost.

(g) Interaction with other research projects

The type of vegetation cover on a certain type of soil gives the best indication of the fertility of the soil. Forest trees are good indicators of fertility of sites. A soil scientist after his soil classification based on soil types relates this to the yields of tree species on the sites. Similarly, an ecologist correlates environmental factors with the yields of tree species. He may also try to adapt a forest growth model for estimation of biomass and the rate of biomass production by tree crops. A tree-breeder certainly requires information on the growth rates and yields of tree species before selecting and recommending a hybrid or a progeny for further trials.

1.2.2 Previous studies on growth and yields of some tropical pines and some eucalypts

Most of the stands of pines and eucalypts to be covered in this study are relatively young, and so, information on their yields is very scanty.

So far, only preliminary information on the performances of these species have been obtained (Kemp, 1969, 1970; Iyamabo et al, 1972; Anon, 1974; Shado and Adegbehin, 1979; Adegbehin, 1980, 1981 and 1983).

However, more detailed studies on Pinus caribaea, for example, have been carried out in other areas. These include growth and yields of P. caribaea in Trinidad by Miller (1969) and yield studies of P. caribaea in Trinidad and Tobago by Lackhan (1972). Studies have also been conducted on growth and yields of other species of tropical pines elsewhere. These include growth and yields of P. patula in the Natal Midlands (Crowe, 1967); site index curves and yields of P. patula in Malawi (Therón et al, 1971); site index curves and yields of P. patula at Sao-Hill, Southern Tanzania, Adegbehin, 1977); diameter distribution yield tables for P. patula in Brazil (Campos, 1981) and yield prediction and increment in P. radiata stands in New Zealand (Beekhuis, 1966).

Some information have also been compiled on the growth and yields of several Eucalyptus species, including E. cloeziana and E. tereticornis, in some parts of East and Central Africa, and in Australia and Brazil (Jones, 1968; Anon, 1970 and Anon, 1979).

1.3 Objectives

i) The major objective of the study is to predict growth and yield for tree and stand variables for E. cloeziana, E. tereticornis and P. caribaea. This will be achieved through

(a) Fitting of diameter distribution with the Weibull function for individual and pooled plot data for the respective species.

(b) Construction of composite model using the stand and site parameters as independent variables and Weibull coefficients as the dependent variables.

ii) Attempts will be made to develop stand volume models for the species and also examine the desirability of fitting intrinsically non-linear models to top height-age and volume-age data for some of the species.

1.4 Scope of Study

Permanent sample plots of E. tereticornis, E. cloeziana and P. caribaea in the study locations comprising of Zaria, Afaka, Nimbia, Miango, Vom, and Ta-Hoss were used. For stem diameter prediction, a minimum of three sets of measurements was considered while the data for top height-age and volume-age curve fittings included at least two sets of measurements.

The scope of study was limited to the available data on selected exotic tree species at the various locations in the savanna areas of Northern Nigeria at the time of investigation. The plantations where data were collected were the oldest and the species studied were among the most promising at the time of investigation. E. tereticornis and P. caribaea, in particular, were the most widely planted species in the areas covered.

CHAPTER 2

GROWTH AND YIELD MODELLING IN FORESTRY

2.1 General

Graphical illustrations used to be the basis for the descriptions of development of stand parameters (such as top height, basal area, mean diameter, volume etc) before the introduction of mathematical descriptions of the growth processes (Fries,1974).

Since the end of the last century, growth models as applied in growth and yield research have undergone some evolutions. A rapid development in the field of growth modelling commenced when regression analysis was introduced in the 1930's. Within the past years, a variety of methods including multi-variate analyses has been successfully applied to growth and yield estimation and this has been made possible by the invention of high speed computers which are capable of handling a large amount of data. The rapid progress in growth and yield research technique has led to the development and application of

growth models for stands as well as for single trees. As a result of this, two special sessions by the International Union of Forest Research Organisation (I.U.F.R.O.) on "growth models for tree and stand simulation" were held in 1973 to discuss achievements and exchange ideas in this field.

2.2 Statistical description of forest data

A forest is a completely complex ecological system made up of biotic and edaphic factors with climatic factors such as rainfall, temperature, wind etc exerting their influences on the former two (Smith et al., 1980). The biotic factors are the living units in the forest and these may be plants or animals. The edaphic factors are the non-living things such as the soil and its components (e.g. mineral constituents). There are always interactions between the biotic, edaphic and climatic factors in a forest ecological system. This means that different types of data may be obtained from a forest, viz: data on litter production, species composition, mineral depletion, biomass production, rate of wildlife depletion and so on. However, with particular reference to the growth of commercial forest trees, data

required from the forest are basically measurements of tree diameters at breast height (d.b.h), tree heights and volumes for the ultimate purpose of calculating standing volume, yield and increment.

Distributions of diameter and height in a forest stand are better described by frequency distribution curves. The shapes of the curves are expected to vary depending mostly on these two parameters, viz: the skewness and kurtosis of the distributions, and these will be discussed briefly.

(i) Skewness

In most cases, tree data such as diameter and height from a stand may not follow exactly normal distribution curves which are symmetrical in shape. In such cases, the curves are said to be skewed (or to have deviated from symmetry). A frequency distribution curve with a longer "tail" to the right of the central maximum than to the left is said to have a positive skewness or skewed to the right. If the reverse is true, it is said to have a negative

skewness or skewed to the left (see Fig. 2.2.1). A frequency distribution curve which is normal has zero skewness. If a low thinning is carried out in a stand having a negatively skewed diameter distribution curve, a new distribution curve will tend towards a positive skewness.

An important measure of skewness is the moment coefficient of skewness (MCSK) defined as the third moment about the mean and is dimensionless. It is given by the expression:

$$\text{MCSK} = \frac{\sum (X_i - \bar{X})^3}{Ns^3} \quad (1)$$

(ii) Kurtosis

Kurtosis is another measure of dispersion of a frequency distribution curve. It is the degree of peakedness of a distribution, usually taken relative to a normal distribution. A distribution having a relatively high peak as that in Fig.2.2 is described as leptokurtic while the flat-topped one is termed platykurtic. The normal distribution curve which is not very peaked or flat-topped is referred to as mesokurtic.

A measure of kurtosis, the moment coefficient of kurtosis (MCKU), uses the fourth moment about the mean and as expressed in a dimensionless form may be written as:

$$\text{MCKU} = \frac{\sum (X_i - \bar{X})^4}{Ns^4} \quad (2)$$

For normal distribution, moment coefficient of kurtosis = 3. Mechanical thinning in an even-aged stand will lead to reduction in the value of coefficient of kurtosis as this will make the diameter distribution curve of the remaining standing trees flatter.

2.2.1 Unimodal distribution and skewness of diameter and height in even-aged pure stand

Typical growth and increment curves are similar to both probability density (frequency distribution) and a probability distribution (cumulative frequency distribution). Fundamentally, an increment curve resembles a unimodal asymmetric probability density. The excellent analogy between growth curve and probability density curve which was recognised by Prodan (1968) strongly suggests the possibility of adapting

a suitable probability function to growth and yield studies. It is further required that the probability density function be flexible to accommodate all practical growth phenomena.

The unimodal distribution and skewness of growth curves can be illustrated by tracing the development of a pure even-aged stand. At the early stage of a plantation, it is common to find a few of the trees growing larger and taller than others. This may be due to better handling of some of the seedlings in the nursery, genetic composition of the original seeds or better planting technique. The net effect of this is that the diameter and height distributions in the stand have unimodal positively skewed curves (Stage A, Fig. 2.2.1). Later on, as all the trees grow under similar conditions with little or no competition, the diameters and heights show a fairly symmetrical unimodal distribution curve (Stage B, Fig. 2.2.1).

As time goes on, when competitions sets in, the diameter distribution curve becomes negatively skewed (Stage C, Fig. 2.2.1). It is noted that with development, the modal regions of the curves shift

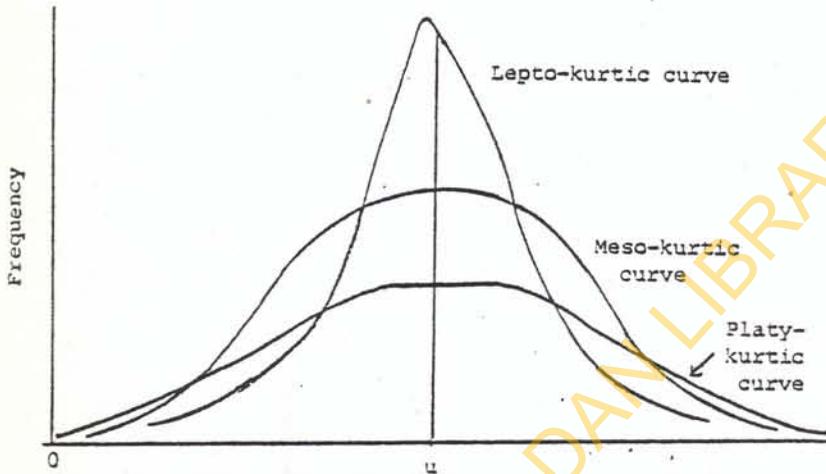


Fig. 2.2 Kurtosis: - the degree of peakedness of frequency distribution curves.

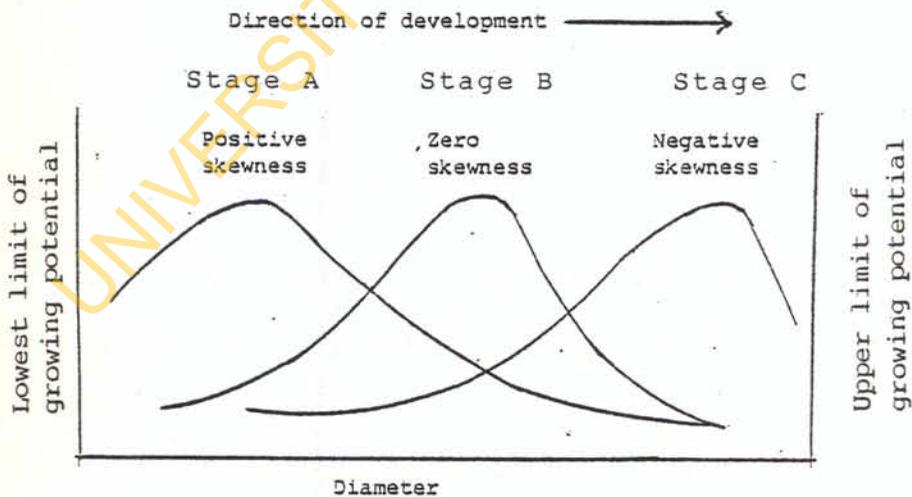


Fig. 2.2.1 Shapes of diameter frequency distribution curves with increasing age in unmanaged pure stand.

from left to right until the stand approaches the upper limit of its physiological growth capacity (Prodan, 1968). The pattern of positive to negative skewness of the curves with increasing age may not be pronounced in regularly managed or thinned pure stands.

The distribution of tree heights on the other hand, moves in opposite direction to that of diameter distribution. The competition for light causes the suppressed trees to grow into the upper storey. This causes an increase in frequencies on the right tail of the curve.

For both diameter and height data, bimodal distributions have also been observed for stands in varying site conditions (Ford, 1975).

2.2.2 Distribution models in forestry

Forest management systems are becoming increasingly intensive and many management decisions are dependent on knowledge of forest stand dynamics. Several studies have been carried out to describe the distribution patterns of forest data, particularly tree diameters, basal areas and volumes.

Most of these studies appear to concentrate more on diameter distribution patterns since the tree diameter is one of the growth parameters that is most accurately measured and can also be used to predict basal area or volume. Diameter distribution models are therefore very important in forest management.

2.2.2.1 Common probability functions for growth and yield studies

Several distribution models have been in use although only some of these are flexible enough to describe the growth curves. These models include normal distribution, lognormal, gamma, beta, Weibull distributions etc and each of these will be discussed briefly.

(i) Normal distribution

A random variable, X , assuming all real values from $-\infty < X < \infty$ has a normal distribution if its probability density function is of the form

$$f(X) = \frac{1}{(2\pi\phi)^{\frac{1}{2}}} \exp \left\{ -\frac{1}{2} \left(\frac{X-u}{\phi} \right)^2 \right\} \quad (3)$$

where $-\infty < X < \infty$, $\phi > 0$

For a normally distributed population, it is expected that 68.27% of the cases will fall between $u - \phi$ and $u + \phi$ and 95.45% of the cases will lie between $u - 2\phi$ and $u + 2\phi$ while 99.73% of the cases will be found between $u - 3\phi$ and $u + 3\phi$.

The standardised normal distribution in most cases does not meet the flexibility desired in growth studies. However, its importance is due to the fact that it is tabulated. Where X has the distribution $N(u, \phi^2)$, it is always possible to obtain the standardised form by transformation. Among a few others who obtained some promising results in the application of normal distribution to growth studies is Gringrich (1967); he used the distribution to describe species composition and diameter data in upland hardwood forests.

ii) Lognormal distribution

A lognormal distribution occurs when a random variable, X , has its logarithm showing a normal distribution. Its probability density function is expressed as:

$$f(X) = \frac{1}{[2\pi\beta]^{\frac{1}{2}}} X^{-1} e^{-\frac{(\ln X - A)^2}{2\beta^2}} \quad (4)$$

where $X, \beta > 0$; $\ln X$ = natural logarithm of X

Bliss and Reinker (1964) found this suitable in describing diameter distribution in some even-aged stands. However, the lognormal functions are of limited use in growth studies as they generate only left skewed curves.

iii) Gamma distribution

A continuous random variable X has a gamma distribution if its probability density function is given by:

$$f(X) = \frac{A^\beta}{\Gamma(\beta)} X^{\beta-1} e^{-AX}; \quad A, \beta > 0 \quad (5)$$

Fig. 2.2.2.1(a) shows the gamma distribution with varying values of β . Gamma distribution is generally noted for generating positively skewed curves. Nelson (1964) found this appropriate for describing diameter distribution in a loblolly pine stand.

iv) Beta distribution

If a random variable X has a density function given by:

$$f(X) = \frac{\Gamma(p+q)}{\Gamma(p)\Gamma(q)} \cdot X^{p-1} (1-X)^{q-1} \quad (6)$$

where $0 < X < 1$, $p > 0$, $q > 0$, then X is said to have a beta distribution. The mean of the distribution is given by:

$$\bar{X} = \frac{p}{p+q} \text{ and its variance } (\phi)^2 = \frac{pq}{(p+q)^2 (p+q+1)} \quad (7)$$

Beta distribution has been used in describing diameter distribution in stands of different species. Among those who have carried out such studies are McGee and Della-Bianca (1967), Lenhart and Clutter (1971) and Burkhart and Strub (1973).

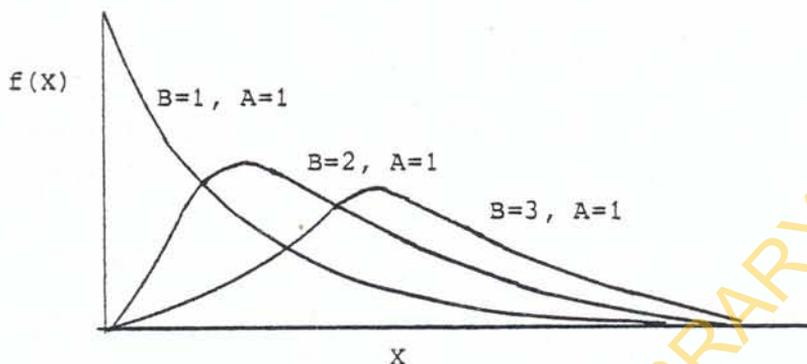


Fig. 2.2.2.1(a) Gamma density distribution with values of $B=1, 2$ and 3 and $A=1$.

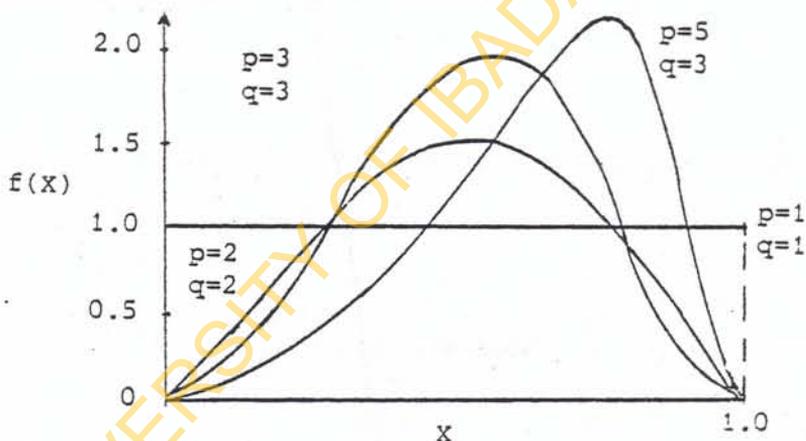


Fig. 2.2.2.1(b) Beta distribution with varying values of p and q .

Beta distribution reduces to uniform distribution over $(0,1)$ if $p = q = 1$ (see Fig.2.2.2.1b). The uniform distribution obtains its name from the fact that its density is uniform or constant over a certain

interval (say a, b). It is also called the rectangular distribution in which case the shape of the density is rectangular.

A random variable, X , with a uniform distribution has the probability density function defined as

$$f(X) = \frac{1}{b - a} \quad (8)$$

where the parameters a and b satisfy

$$-\infty < a < b < \infty \quad (\text{Fig. 2.2.2.1c})$$

If X is uniformly distributed over (a, b) , then the mean of the distribution is given by

$$\bar{X} = \frac{a + b}{2} \quad \text{and its variance } (\sigma^2) = \frac{1}{12}(b - a)^2 \quad (9)$$

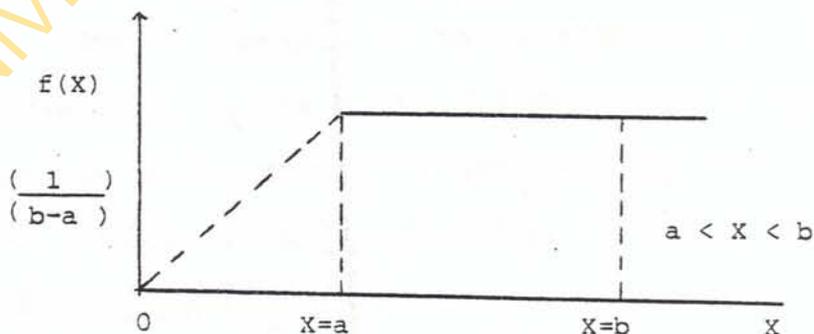


Fig. 2.2.2.1(c) Uniform density distribution

The gamma and beta distribution functions have their density functions highly flexible in shape and are therefore more promising for adaptation in growth studies.

(v) The Weibull distribution

In the study of extreme values, Fisher and Tippett(1928) presented a probability distribution which was independently derived by Weibull (1939) in the studies on reliability test of materials. The emphasis placed on reliability analysis following World War II gave prominence to the Weibull's work and this distribution came to be associated with his name. The Weibull distribution has been described as an excellent function in quantifying the structure of both even-aged and uneven-aged stands (Bailey and Dell, 1973 and Bailey, 1974). Among many other researchers who have also applied the Weibull function for predicting the stand structure are Alan et al.(1975), Rustagi (1978), Yang et al.(1978), Okojie (1981) and Hyink et al. (1983).

The Weibull probability (cumulative) distribution function is defined as:

$$F(X) = 1 - e^{-(X/b)^c} \quad (10)$$

where:

X, b and $c > 0$

b = scale parameter

c = shape parameter.

The Weibull distribution is the most flexible in its scale and shape parameters and very applicable in growth studies. Both parameters have a numerical domain ranging from zero to positive infinity ($0 < b, c \leq \infty$)

Bailey and Dell (1973) and Rustagi (1978) used the modified Weibull function for quantifying diameter distribution in both even-aged and uneven-aged stands. The modified function includes 'a' parameter which indicates the beginning of the point of distribution. The cumulative distribution function of the 3-parameter Weibull is then expressed as:

$$F(X) = 1 - \exp \left(- \left(\frac{(X - a)^c}{b^c} \right) \right) \quad (11)$$

Generally when $c < 3.6$, the probability density function is positively skewed and when $c = 3.6$ the Weibull approximates a normal distribution. However, when $c > 3.6$, the distribution becomes negatively skewed. For natural forests (all-aged stands), the value of $c \leq 1$ is anticipated (Fig. 2.2.2.1d) and if $c > 1$, a unimodal curve typical of the structure of even-aged stands occurs. For unthinned even-aged stands on a given site, the value of 'c' is directly related to age (Rustagi, 1978).

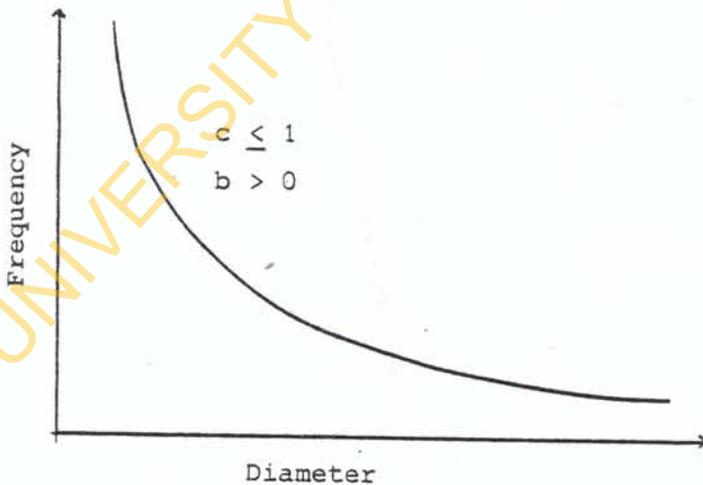


Fig. 2.2.2.1(d) Weibull distribution and values of 'b' and 'c' for all-aged forests (Rustagi, 1978).

vi) Other distribution models

Other systems and distributions which were found useful in describing curve shapes are the reversed J-shaped exponential functions by Meyer (1952) and later by Schmelz and Lindsey (1965). Others which include the mound shape are the Gram-Charlier series (Meyer, 1930); Pearl-Reed growth curve (Nelsen, 1964; Osborne and Schumacher, 1935); the Pearsonian curves (Schnur, 1934) and Johnson's System B-model (Hafley and Schreuder, 1977; Monness, 1982).

2.2.2.2 Growth and yield empirical prediction functions

As mentioned in the earlier part of this chapter, these are mathematical or graphical descriptions of the development of forest or stand parameters such as top height, basal area, mean diameter, volume etc. These can be broadly classified into linear models, intrinsically linear models and intrinsically non-linear models.

(i) Linear growth models

These are represented by the type

$$Y = a + bX \quad (12)$$

where X = age (the independent variable) and Y , the dependent variable, is any growth parameter such as tree height, diameter, volume etc and a and b are constants.

For young stands of some fast-growing species, it is possible to obtain a high correlation between the dependent variable, Y , and age. However, as the stands age, these types of models do not give good fits.

Polynomial fitting also belongs to the class of linear models as their coefficients can be expressed as linear functions. It is given by the general expression:

$$Y = a + b_1X + b_2X^2 + b_3X^3 \dots + b_nX^n \quad (13)$$

where a , b_1 , b_2 , b_3 and b_n are constants.

Models of this type could be used to predict the total volume production from top height which then serves as an independent variable. It could also be used for the construction of site index curves in which case top height is predicted from age. It may be possible to obtain a better fit for a given set of data by increasing the number of terms.

(ii) Intrinsically linear models

These are non-linear in their original forms, but become linear when transformed. In this class of models is the Schumacher equation:

$$H = H_m \cdot e^{(b / A^k)} \quad (14)$$

where H = Dominant height (m)

H_m = Maximum height a species could reach
(in m) and b is a constant.

A = Age of stand in years

e = Exponential constant (2.71828)

For many tree species, an assumed value of $K = 1$ will give a satisfactory fit (Anon, 1980). For $K = 1$, a linear version of the equation can be obtained by transformation using natural logarithm (to the base e) as follows:

$$\ln H = \ln H_m + b/A \quad (15)$$

(iii) Intrinsically non-linear growth models

For this class of models, in most cases, estimation of the constants are based on the non-linear least square method using the iterative procedure (Marquardt, 1963) or the linear approximation method (Box and Jenkins, 1976).

It is necessary to examine the general biological principles involved in the growth processes of trees in even-aged stands to fully understand the intrinsically linear and non-linear models. Assmann (1970) and many other authors have already discussed this subject and explained how the growth processes of trees in even-aged stands are satisfied by non-linear models. The growth curves have been found to have these two characteristics:

- (a) They are asymptotic with straight line as age approaches infinity.
- (b) There exists one point of inflection on the curve at an age which varies from species to species and with site quality within species.

This means that the current annual increment increases up to the age of point of inflection, becomes maximum at this age and starts to diminish there-after.

A good account of the various growth functions used in forest yield studies has been given by Richards (1959). The growth functions developed by Richards are extensions of the work by Bertalanffy (1941) and have been extensively used in biometrics and other related fields. Bertalanffy's growth model is a multi-molecular growth function expressed as:

$$V = a \{1 - e^{-c(A)}\}^{(1-d)^{-1}} \quad (16)$$

where V = Stand volume (m^3/ha)

A = Age in years and a , c , and d are constants to be estimated while e is the exponential constant.

Several other growth functions of this type have evolved over the years with the advent of fast electronic computers facilitating their applications. Some of these were modified and used by Nokoe (1980) to fit volume-age curves to growth data of Douglas-fir at British Columbia, and the fitted curves were found to compare favourably with the earlier hand-drawn curves. The growth functions used by Nokoe (loc. cit.) include the

Multimolecular,

$$v = a\{1 - e^{-cA}\}^d \quad (17)$$

Modified multimolecular

$$v = a\{1 - be^{-cA}\}^d \quad (18)$$

Autocatalytic or Verhulst or Logistic

$$v = a\{1 + e^{-c(A - I)}\}^{-1} \quad (19)$$

Gompertz

$$V = a e^{-e^{-c(A-I)}} \quad (20)$$

"Grosenbaugh's reparameterized" Pearl-Reed

$$V = a / (1 + z \exp(-(cM + c^2(K-\frac{1}{2})M^2 + gM^3))) \quad (21)$$

In Models (17) - (21)

V = Stand volume (m^3/ha)

A = Age or age-group mid-point in years and

a, b, c, d, k, g, z, M and I are

parameters to be estimated while e is

the exponential constant.

Among the other growth functions in use are:

$$V = a \left(1 - e^{-c \cdot A} \right)^3 \quad (\text{Mitscherlich}) \quad (22)$$

$$V = a \left(1 - e^{-c \cdot A^I} \right) \quad (\text{Modified Weibull}) \quad (23)$$

All parameters have the same interpretations as for Models (17) - (21).

For a given species, the parameter, a , in Models (17) - (23) is an indication of site level and is expected to decrease with decreasing site quality as confirmed by Nokoe (1980). The parameter, I , for the Verhulst, Gompertz and Pearl-Reed models represents the age at which current annual increment (C.A.I) reaches its peak. In an earlier paper, Nokoe (1978) demonstrated the flexibility of the modified Gompertz function as well as providing biological significance or interpretation to the behaviour of the coefficients.

Yang et al (1978) in fitting curves to height-age and volume-age data of spruce used five of the growth functions viz: the Gompertz, Verhulst or Logistic, Von Bertalanffy, Mitscherlich and the modified Weibull functions and found that all the five chosen functions fitted reasonably well to the spruce height growth data. It was however noted that the Gompertz and the modified Weibull functions performed better than the other three in terms of the residual root mean squares. On the volume growth data the performance of the five functions varies

from excellent to poor. The modified Weibull and the generalised von Bertalanffy functions proved excellent with the lowest residual mean squares while the Gompertz was satisfactory. The Logistic was poor while the Mitscherlich function performed below standard as it is not as flexible as others.

2.2.3 Stand growth with age

(i) Height/diameter relationship

In even-aged stands, the relationship between height and diameter is usually curve-linear (Chapman and Meyer, 1949 and Loetsch et al., 1973).

When several sets of height-diameter data from a given managed even-aged stand are plotted separately, but on one graph sheet, the height-diameter curves shift upwards and towards the right with increasing age (Fig. 2.2.3a).

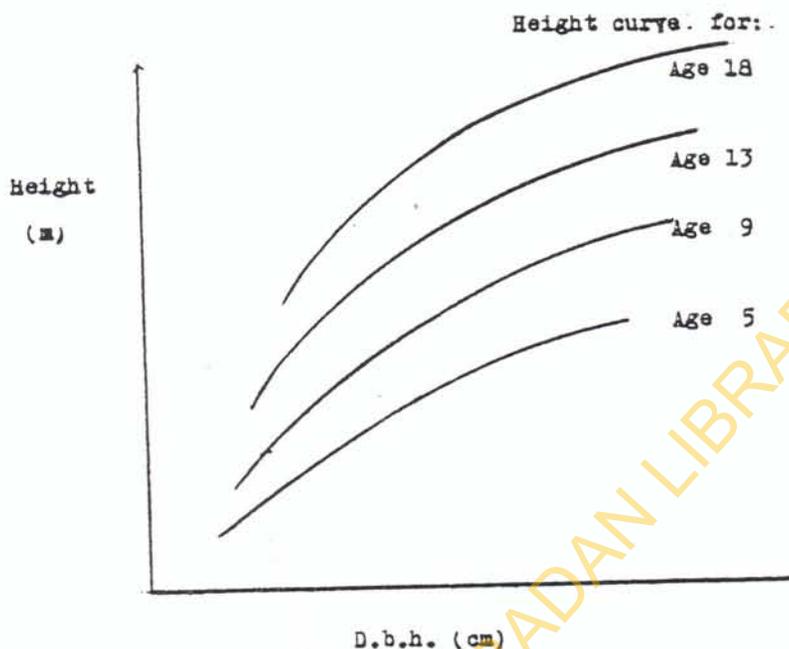


Fig. 2.2.3a

Relationship between height and diameter with increasing age.

- (ii) Stocking or number of trees per hectare with age

The relationship between stocking and age has been described by a decreasing trend (Prodan, 1968). Fig. 2.2.3b shows that the number of stems per hectare decreases with increasing age. This is particularly true if the forest is managed on a long term rotation basis.

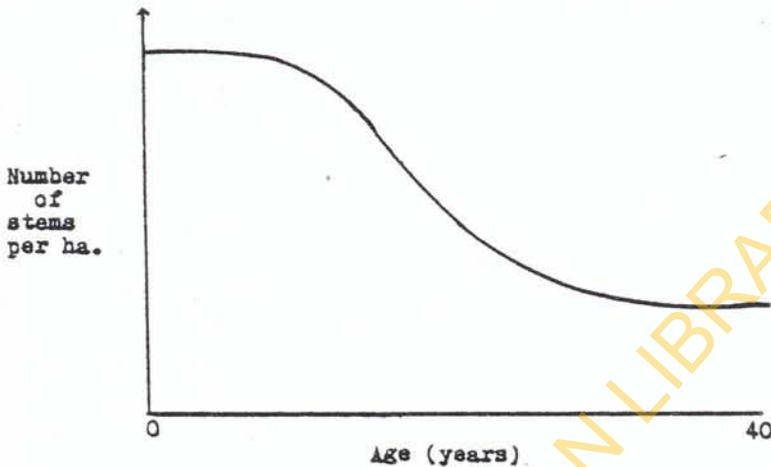


Fig. 2.2.3b Relationship between stocking and age in a managed even-aged forest.

(iii) Top height and age

The relationship between top height and age shows an increasing trend (Husch et al, 1963; Loetsch et al., 1973). However, as the age approaches infinity, the relationship follows the sigmoid shape (Fig. 2.2.3c). The relationship between total volume production and top height also follows this pattern.

(iv) Total volume production and age

For a given species and within the same site quality, the relationship between total volume

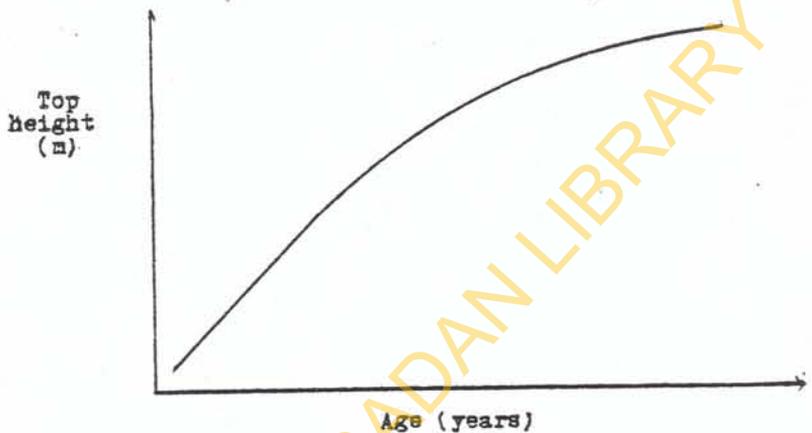


Fig. 2.2.3c Relationship between top height and age in a forest stand.

production and age is also an increasing function which follows the sigmoid shape as age approaches infinity. However, when different site classes are considered for a given species, the relationships are represented by a series of yield curves (Fig. 2.2.3d). For different tree species in an area of the same growth potential it is common to have different total volume production/age curves (Prodan loc. cit.).

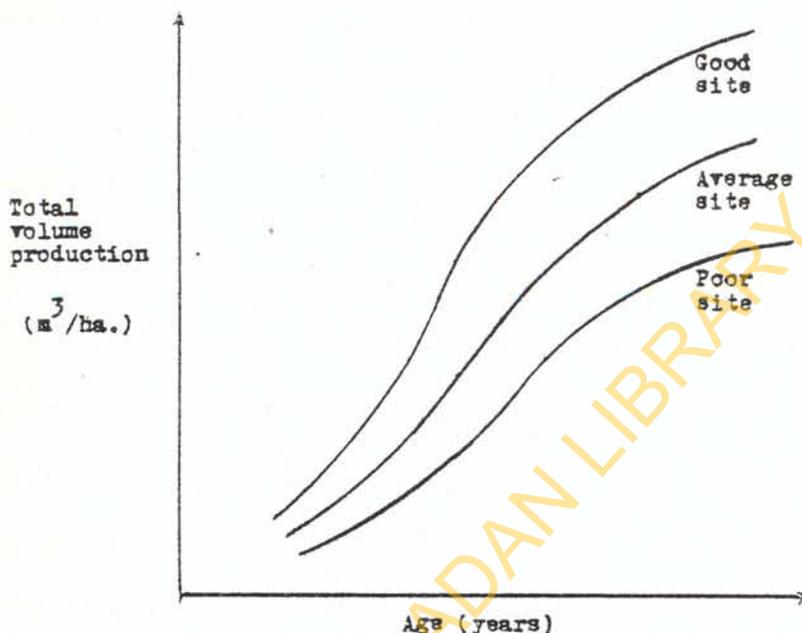


Fig. 2.2.3d Relationship between total volume production and age

2.3 Growth and yield simulation models

Computer models of forest stands first appeared in the early sixties and have since proliferated. Forest modelling is a unit in the natural resource systems in which computer simulation techniques offer potential for improved and informed management. Different types of models have been developed depending on needs. The form of a model is usually dictated by the quantity and quality of data available for design, calibration, validation and operation.

2.3.1 Classification criteria for simulation models

Past efforts by modellers to pursue a particular objective rather than a particular modelling philosophy have not given way to a well defined classification system. Munro (1974) has evolved the most recent three classification criteria which allow for efficient and accurate communication and understanding of model classification, viz: classification by model structure, classification by competition processes and classification by state variables.

(a) Classification by model structure

The structure of a stand model may be defined as

$$Y (t + 1) = M (Y (t)) \quad (24)$$

where Y is a set of stand variables at time t and M represents the functional relationships (e.g. growth, competition etc) incorporated in the model. The stand variables, Y , are generally made up of:

- D - Decision variables or those variables that are controlled directly. These include management activities such as undisturbed growth, harvesting or spacing.
- S - State variables - variables that fluctuate in response to decision, or remain constant but uncontrolled. Typical of these are site, density, stand age, average diameter, average height etc.

The nature of stand variables, their interactions, and the interactions of the components constitute the structure of a model.

Generally, one rationale for constructing a model is simply to put the available information in a tractable form. Tractability refers to the relative ease of analysis and manipulation of the behaviour of the model. The tractability of a model generally depends on its underlying mathematical structure. If a model is expressed in a mathematical

structure that makes it amenable to manipulation with algebra or calculus, it is said to be analytically tractable. A decision problem involving an analytically tractable model may be solved by a classical optimization technique. If a model has a linear, continuous, and simultaneous structure, it can be analysed using linear programming. If it is non-linear but still continuous and simultaneous, non-linear programming techniques might be used. For a model with a sequential and Markov structure, analysis and solution may be achieved through dynamic programming. When none of these classical structures can be identified, as is often the case with stand models, the model can only be analysed with repeated experimentation or pattern search techniques.

(b) Classification by growth and competition processes.

In growth modelling, stand development is usually considered to be the product of tree growth and competition, with competition acting in a feedback as a suppressor on the growth process. Other exogenous

factors such as insect infestations, wild fire, silvicultural treatments and harvesting that also affect the stand structure are rarely included as dynamic elements. Although these factors modify the state variables, they are not easily quantified, and as such, the level of detail at which the growth and yield processes are modelled is limited by the nature of the information obtained in the state variables. Different strategies to integrate growth and competition processes into the forest stand models will be discussed in detail under classification by state variables.

(c) Classification by state variables

Stand models are usually classified by variables used to model the state of the stand and this leads to the types of forest stand models as recognised by Munro (1974).

2.3.2 Types of forest stand models

Munro (loc.cit.) has given a break-down of forest stand models diagrammatically as follows:

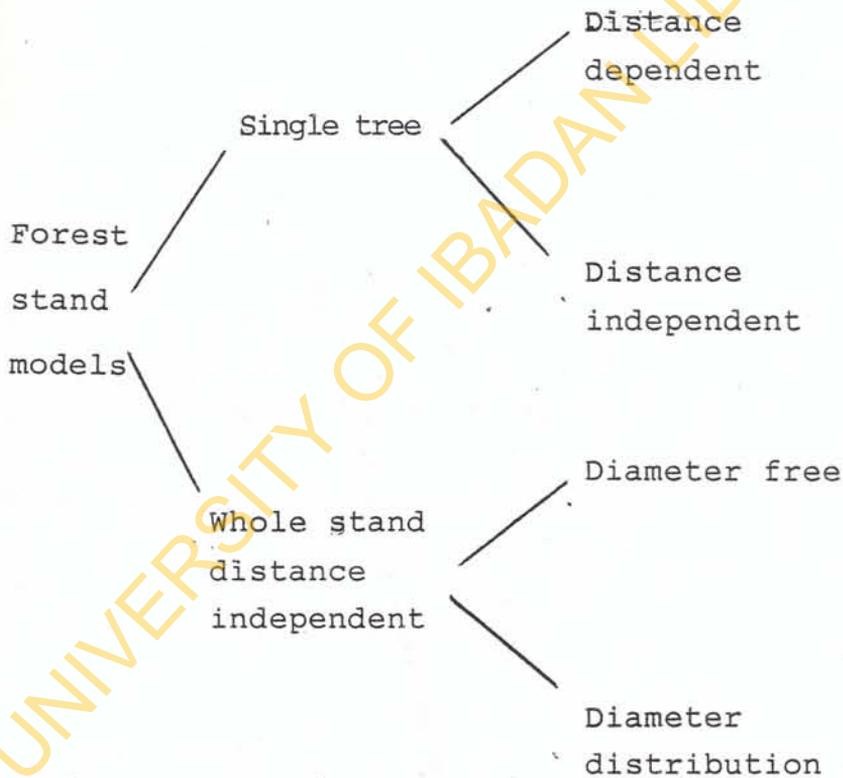


Fig. 2.3.2 Basic forest stand modelling philosophies Munro(1974)

2.3.2.1 Single tree models

Under this classification scheme, it is assumed that the primary unit of stand modelling is the single tree. The single tree models may be of two types:

- Distance dependent in which case inter-tree space becomes a necessary parameter.
- Distance independent, implying that inter-tree space is not a necessary parameter.

Each of these sub-divisions will be discussed in detail with given examples.

(a) Single tree/distance dependent models

These require data on the location of every tree on the plot to be investigated. Using these data, a single tree's competitive status within the stand is characterised by examining the nearness and size of the surrounding trees.

These models, although sometimes radically different in detail, are based on the same concept of determining competition index within the stand to correct for potential growth. Each modeller has

incorporated techniques or capabilities into his model and these are more or less unique and, in specific circumstances, extremely useful.

The earliest and perhaps the best known model of the single tree distance dependent model is that of Newnham (1964). The state of his simulated stand was represented by the spatial co-ordinates and diameters of individual trees. Diameter increment was predicted as a function of d.b.h. and age, and reduced by a crown overlap competition index.

The major problem had been the computation of a reliable measure of the crown overlap competition index. The competition index itself is dependent on the degree to which the competition circle of the subject tree is overlapped by competition circles of surrounding trees. The competition circle of a tree is usually defined as some function of d.b.h. of the tree. The actual amount of overlap (i.e. competition) has since then been expressed by various modellers in units of area, circumference or angles.

Lee (1967) improved on Newnham's model for lodgepole pine by increasing the number of trees in the simulated stand and predicting tree volume as a function of height and basal area without making significant changes in the state representation or growth and competition processes.

Bella's (1970) aspen growth model is another modification of the basic Newnham's approach where concerted efforts were made to improve on the estimate of the competition index which was then used to correct for potential height growth.

Lin's (1970, 1974) Douglas-fir and Western hemlock models showed a different strategy for modeling competition. Lin introduced the concept of growing space index, which measures the relative space or resources available for tree growth, and change in growing space index which indicates change in space or resources available to the tree, e.g. after thinning. He then predicted net diameter increment free from competitive stresses.

Models developed by Mitchell (1969, 1971, 1975 and 1975a) have the stand state in greater detail than many other models. Bole height is maintained as a state variable. The crown of the simulated tree is modelled explicitly by recording individual branch size and folial volume. Estimates of bole diameter and volume are based on crown size. The potential height growth free of competition of a particular tree is based on a site index curve. Branch extension and crown size are dependent on height increment. Foliar volume is computed and used to predict the quantity and distribution of bole diameter increment. These models have been tested and applied extensively by the British Columbia Ministry of Forests.

In the program FOREST developed by Ek and Monserud (1974) to simulate the growth and reproduction of even - and uneven-aged mixed species forest stands, stand state is represented by the height of individual trees. Potential height increment is predicted from site index curves and potential diameter increment is calculated from height increment. Both

height and diameter increments are modified by
by the crown overlap competition index .

Competition ends in mortality of a stem when the probability of survival, calculated as a function crown ratio and competition index does not exceed a generated uniform (0-1) variate. An unusual feature of FOREST is that it simulates regeneration and understorey development explicitly.

Arney's (1972) Douglas - fir model simulates stand state as individual tree heights and diameters at each whorl down the bole. Crown length and volume are computed as a function of the number of live whorls. Potential height growth from a site index curve is modified by a function of crown volume. Diameter increment is allocated down the bole at each whorl as a function of a crown overlap competition index evaluated at each whorl. This dynamic representation of the crown leads to considerable control over the form and size of the simulated trees.

Hegy's (1974) BUSH model of Jack pine stands follows Arney's approach, inasmuch as the growth of

individual trees is simulated by incrementing annually height growth and incrementing diameter at successive internodes along the stem. Potential annual increments are reduced according to the amount of competitive stress to which the tree is subjected. Hegyi derived a diameter-distance competition index for each tree. Hence the use of Hegyi's index implies that a tree may be subjected to competition even in the absence of crown overlaps.

Daniels and Burkhart (1975) in their Loblolly pine model similar in design to the FOREST model of Ek and Monserud (1974) used Hegyi's diameter-distance competition index for converting potential diameter and height increments to actual increments.

All the single tree/distance dependent models have the merits of producing very detailed information about the structure of the stand but their major disadvantage lies in the difficulty of calculating a meaningful biological measure of competition and in the excessive computer time required to execute such models. A large amount of storage for tree

position records and lengthy calculations or "search" time are required to assess the potential tree - to - tree competition. Another limitation in the use of such models is the usual lack of information on stem-charts except for the most intensively monitored permanent sample plots.

(b) Single tree/distance independent models

These models do not require tree co-ordinates. Trees are grown in dimensions individually, or in groupings of similar diameters, according to some mathematical functions. A tree's competitive status within the stand is determined by comparing the tree's size to all other trees in the stand.

Models constructed under this philosophy, unlike those that are distance dependent, do not have much similarity in concept. Techniques of assessing and assigning growth and mortality differ from model to model and also from one modeller to another. They vary from the obviously simple regression type of Lemon and Schumacher (1962), where periodic d.b.h.

growth is expressed as some function of stand competition, site and existing tree size, to extremely complicated stochastic models such as the one proposed by Dress (1970). Models constructed according to either extreme or between the extremes seem to provide satisfactory results for the purposes for which they are intended.

The usual strategy is that potential growth is computed for the aggregate stand and then allocated among the trees in the d.b.h. list. Stand level competitive stress is usually incorporated in the potential growth equation while growth is allocated among the trees based on their competitive position in the stand. Mortality is inadequately corrected for as it is usually predicted as a continuous variable although most models resort to stochastic experiments to test the survival of each tree.

With the single tree distance independent model, e.g. STANDSIM (Opie, 1970), growth is accomplished by calculating gross increment of basal area per hectare and redistributing this among the individual trees on the assumption of even spacing. Self-thinning

of the smallest trees occurs if the number of trees exceeds a maximum calculated for stand age and site.

TOPSY, Goulding's (1972) model of Douglas-fir growth represents the simulated state as a list of stem diameters. Although heights are not recorded for each tree, the dominant height for a stand age is computed from site index curves and used as an independent variable in the growth component involving the average stand diameter. The diameter increment function is calculated net of competition, being corrected for competitive stress. The total diameter increment is obtained via the number of trees per hectare and then allocated among the stems according to a linear function. This method is similar to that of Opie (1970) except that mortality is corrected for by a stochastic procedure.

Stage's (1973) PROGNOSIS model is a widely used single tree distance independent model. As with Opie's and Goulding's model, the stand state is represented as a d.b.h. list, with height and crown dimensions also recorded. The key growth component is the annual basal area increment computed from d.b.h., site,

species type, crown ratio, relative stand density and the percentile of the tree in basal area distribution. Height increment is calculated as a function of radial increment, species type, d.b.h. and height. A special feature of the PROGNOISIS is its incorporation of the stochastic nature of growth into the calculation of basal area increment with little or no additional computational load.

The single tree/distance independent models have a lot of advantages. They are designed to produce detailed tree and stand information. Besides providing inventory summary statistics, stand and stock tables are usually computed. The models can be used to study the response to some silvicultural treatments such as spacing, thinning and in cases fertilizer application. Elimination of stem charts in the models has resulted in fast computing time permitting testing of many alternative hypotheses of management. Hence these models are essential in development of management decision-making models which must explore several alternatives in search of an optimum.

The major disadvantage of the single tree/distance independent models is their inability to predict the growth of a specific single tree with any reliability, and as a result of this the models can not be used to effectively examine individual trees for growth parameters.

2.3.2.2 Whole stand/distance independent models

These do not use individual tree data directly. They are initialised by and subsequently provide average stand information. Regression functions used to determine stand growth parameters fall under this class of models. Although the normal conventional yield table is an example of this type of model, it is less complex than modern models of the same type. Nowadays, with high computer calculation capability, models of the whole stand/distance independent types are more sophisticated with the introduction of complicated mathematical functions permitting solution of yield functions with virtually an unlimited input of parameters. The whole

stand/distance independent models may be further classified into two categories - the whole stand/diameter free models and the whole stand diameter distribution models.

(a) Whole stand/diameter free models

Models of this type do not use or provide diameter distribution data. They are usually developed for pure managed natural or even-aged stands and are initialized by site index and stand variables such as stand age, average or quadratic stand diameter, and the basal area or total number of trees per ha. They do not use or provide diameter distribution data.

Among one of the earliest models in this class is the type developed by Myers and Godsey (1968) for the computation of yield tables for managed even-aged timber stands. The model consists of a FORTRAN computer program called YIELD in which a THINI program was incorporated. The input includes such parameters as site index for the species, interval between intermediate cuts, the stocking levels, average d.b.h.

before and after thinning, mean height before and after thinning in relation to average d.b.h., growth equation and number of trees for which growth equation makes projection etc. The output includes different sets of yield tables showing the stand variables at varying density for different site indices before and after thinning.

Myers (1971) later improved on this by developing a FORTRAN computer program called PONYLD which is essentially the same as the YIELD and THINI programs but the sets of yield tables produced show results of various management alternatives for decision-making. PONYLD can be modified in many ways to answer the question "what would happen" if there is a change in thinning regime.

Another recent model YIELD, developed by Hepp (1982) is a more advanced form of PONYLD. This has provision for sensitivity analyses for several decision criteria including present net work and internal rate of return.

The model RMYLD (Edminster, 1978) is another example of this class of models. Average stand

diameter and height, number of trees per ha and rate of mortality are projected over 10-year periods as a function of age and density, thinning being simulated to retain a specified stand density.

Hoyer (1975) describes a Douglas-fir simulator where basal area and number of trees per ha are the state variables. Basal area increment is predicted as a function of current basal area, site and age. Different growth relationships are included for thinned and unthinned stands and competition is incorporated directly into the basal area increment function via the current basal area. Mortality, computed as a function of normal stocking reduces the number of trees per ha.

The Douglas-fir managed yield simulator (DFIT) of Bruce DeMars et al. (1977) appears to be one of the most highly developed model of this class. Stand state is represented as the number of trees per ha, stand basal area, and the diameter of tree of average basal area. Potential height growth obtained from a site index curve is converted to volume growth and modified by a density dependent factor which is the

ratio of average basal area to the maximum limited basal area of the stand.

However, with less complicated calculations as in DFIT, Brodie et al. (1978) present a very simple model where the state of the stand is simply the stand volume. Volume at some future time is predicted as a function of the present stand volume and age. Competition is reflected in the growth functions which were fitted to normal yield tables. Periodic mortality was predicted as a function of age and the current number of trees per ha.

(b) Whole stand/diameter distribution models

These use smooth functions such as the Weibull or beta probability density functions to characterise the diameter distribution as discussed in the earlier part of this chapter. The parameters of these distributions are then modelled as functions of site and age.

Simulators of this type have mostly been limited to pure unmanaged even-aged stands. Diameter

distribution models differ chiefly in the function used to describe the distribution. Stand table projection systems model diameter distribution as a discrete probability distribution based on the initial observed diameter frequency distribution.

Burkhart and Strub (1973) employed the beta distribution technique along with other equations to predict, for Loblolly pine stands, the minimum and maximum tree diameters at breast height and the relative number of trees by diameter classes between the two extremes. Other parameters predicted include mean tree total height by diameter classes for a given age, average height of dominant trees for the stand and the expected diameter class and height frequencies.

Clutter and Allison (1973) in their growth studies of Pinus radiata in New Zealand predicted initial diameter distribution based on the Weibull distribution model. Subsequent stand growth was then simulated on an annual basis through functions which predicted gross basal area increment, basal area mortality and stems per hectare mortality. Although

this system is basically a stand-level simulator, it produced detailed information each year on heights and frequencies by diameter classes.

Rudra (1968) represents the state of a stand with a diameter frequency distribution but models the growth process as a stationary Markov chain. The probability of a tree moving from one diameter class up to the next adjacent diameter class is a function only of its present diameter class and independent of stand age, structure or any other variables. Competition and mortality are essentially ignored. Rudra's model, which attempts to simulate stand growth with a stochastic process, seems unlikely to fit well into forest stands which themselves do not meet Markov chain assumptions.

Bruner and Moser (1973) also used a Markov chain approach to predict future diameter distributions, number of survivors and mortality trees, and number of harvested trees. The model suffered from the same questionable assumptions as Rudra's model.

Alder's (1979) model represents the stand state by a list of diameters corresponding to a specified

cumulative probability that a certain diameter would not be exceeded. Essentially, the trees in the list are representative trees of specified percentiles of the diameter probability density function. Dominant heights from a site index curve at a given age serves as an input in the growth model. The maximum potential basal area for the stand age is computed from stand dominant height. Competition is corrected for, and the ratio of current stand basal area to maximum potential basal (relative basal area) defines the potential for growth of the stand as a whole. The predicted stand dominant height from the site index curve, the relative basal area and the dominance ratio (ratio of tree diameter to mean diameter of dominant trees) are independent variables in a non-linear function defining the tree diameter increment. Each of the representative trees in the tree list is incremented. The effect of thinnings on the diameter list was modelled as a function of the ratio of stocking after thinning to stocking before thinning. The computer program for the model is called PYMOD written in a FORTRAN language.

Okojie's (1981) research work on stand development in the Meliaceae was based on the whole stand/diameter distribution model using the concept of the three-way Weibull distribution function. The models obtained from the predictions make it possible to describe diameter distribution in the stand, particularly within the range of ages covered by the field data.

The advantages of the whole stand/distance independent models are their ability to utilize conventional inventory information, minimum use of computer time and their simplicity. The major demerit is the lack of information on specific individual trees.

CHAPTER 3

THE STUDY AREA AND MANAGEMENT HISTORY

3.1 Study locations

The study locations are Kabama (Zaria) and Afaka both in the Northern Guinea Zone and Nimbia in the Derived savanna zone; other locations are Miango, Vom and Ta-Hoss on the Jos Plateau (See Fig. 3.1). Table 3.1 shows the locations and site characteristics of the study area. Further details regarding the original vegetations of the study areas have been given by Keay (1959).

3.2 Establishment of plantations and previous management practices

Establishment of exotic tree species including pines and eucalypts in the savanna zones of Nigeria commenced mainly with species trial procedure in 1959. The species trial procedure was made up of three stages, viz: the elimination trial stage, growth trial and plantation trial, following the pattern which had earlier been adopted in Uganda and Zambia (Kemp, 1969).

Fig. 3-1. Vegetation zones of Nigeria and locations of study areas.

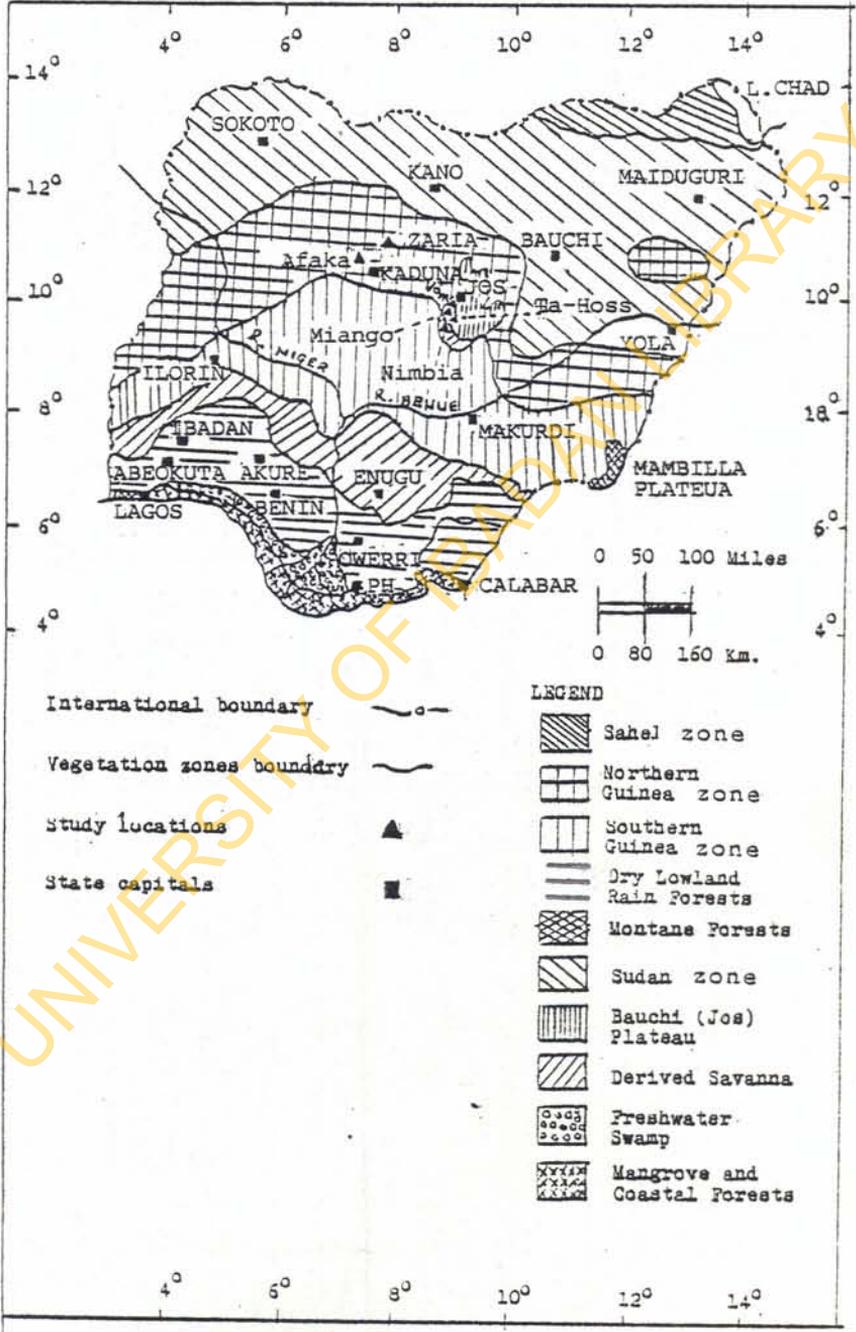


Table 3.1 Site characteristics of study areas.

	STUDY AREAS					
	Kabama (Zaria)	Afaka	Ninbim	J O S P L A T E A U		
				Miange	Vom	Ta-Hess
Location	Latitude 11° 8'N Longitude 7° 42'E	Latitude 10° 37'N Longitude 7° 31'E	Latitude 9° 30'N Longitude 8° 34'E	Latitude 9° 51'N Longitude 8° 52'E	Latitude 9° 43'N Longitude 8° 47'E	Latitude 9° 38'N Longitude 8° 44'E
Altitude (m)	650	600	600	1300	1250	1250
Mean annual rainfall (mm)	1070	1290	1750	1570	1370	1348
Rainy days/year	170	180	220	180	190	185
Mean maximum temperature (Hottest months)	35°C (March, April)	35°C (April, May)	36°C (March)	31°C (March)	31°C (March)	31°C (March)
Mean minimum temperature (Coldest months)	14°C (December, January)	14°C (December)	15°C (December)	13°C (December, January)	13°C (December, January)	13°C (December, January)
Mean annual temperature	25°C	25°C	26°C	22°C	22°C	22°C
Soil types	Ferruginous reddish brown tropical sandy clay loam over plinthite layer pH range : 5.3 - 6.6	Ferruginous reddish brown tropical sandy loam to sandy clay loam, over plinthite layer pH : 5.3 - 6.2	Eutrophic dark brown soil, loam to clay loam, derived from basalt. pH : 6.0 - 6.8	Eutrophic reddish brown soil, derived from basalt, mainly clay loam. pH : 5.2 - 5.6	Eutrophic reddish brown soil, derived from basalt, mainly clay loam. pH : 5.2 - 5.6	Eutrophic reddish brown soil, derived from basalt, mainly clay loam. pH : 5.2 - 5.8

Sources: Kemp(1969) and Iyamabo et al.(1972)

The design for the species elimination trials (S.E.T.) was a randomised block with four replications and nine trees per plot, but in addition to this, one larger plot of thirty-six trees of each species in each trial was established for continuous observation. As a result of high mortality of most of the species within the randomised blocks, the number of trees per plot was increased from the original 9 to 25 in the subsequent trials, but planting espacement remained at 1.8 m by 1.8 m.

The species successful in the elimination trial experiments (i.e. considering height growth and survival) were selected for species growth trials (S.G.T). The standard design for the S.G.T. was a randomised block with four replications and a hundred trees per plot, i.e. 10 by 10 rows of trees. At the same spacing of 1.8 m by 1.8 m, this gives an individual plot size of about 0.032 ha. Silvicultural practices in the trial plots consisted mainly of weeding and this was carried out when necessary. There was no fertilizer applied although

Kemp (1969) considered that a single application of the standard NPK fertilizer at the time of planting and commercial borate in some areas during or after planting could have led to better growth.

Following the S.G.T. was the species plantation trial (S.P.T.) stage. The plantation trials were restricted to those species which had already passed the S.G.T. stage and a period of five years of good performance in growth trial plots was accepted as sufficient evidence of the suitability of a species for plantation trial. Nearly all the S.P.T. experiments initially consisted of single 0.032 ha plots which were sufficiently large to permit accurate measurement of crop performance under a standard treatment system. Although a few large plantations were established before and during the intensive species trials, it was not until 1968 that plantations larger than one hectare were established in most of the trial areas where certain species had been earmarked as promising. The espacement adopted was later increased from 1.8 m by 1.8 m to 2.4 m by 2.4 m and finally to 2.7 m by 2.7 m to allow for

mechanised operations, especially weeding, in two directions. However, in some instances, before the 1959 intensive species trials, spacings wider than 2.7 m by 2.7 m had been used.

The three species covered in this study, i.e. E. tereticornis, E. cloeziana and P. caribaea, are among the most promising in the plantation trials. E. tereticornis had its seed source from Mysore (India) while E. cloeziana seeds came from Queensland (Australia). Intensive pine provenance trials commenced in 1968 in the savanna areas, but an indication of the best provenances had been given from the earlier species trials. The provenance of P. caribaea that has proved the most outstanding of all the provenances tried is from British Honduras and is of the variety hondurensis (Ojo and Shado 1973). All sample plots of P. caribaea in all study locations were in this particular provenance.

CHAPTER 4

BASIC DATA AND DATA SCREENING PROCEDURES

4.1 Data source and sample plot records

The data of tree diameters, heights and volumes for this study were collected under the close supervision of the author from well maintained research plots with properly kept records. All the sample plots were sited in even-aged pure stands. Each plot has its own record in a binder. More-over in a plot binder, each tree is assigned a permanent number in such a way that each tree within a plot has its own record for every girth measurement. Every plot also has a plot chart showing the plot orientation and the tree numbering pattern as they appeared on the field. At every assessment, a girth assessment form known as the "general register" which contains the previous measurements is used for recording the girth of each tree following the

permanent tree numbers. In this way, any error in girth measurements is easily detected and corrected right on the field. Any tree thinned is assigned a blank space or zero in the binder during the next and subsequent measurements. For the purpose of this study, the girth figures in the "general registers" were converted to diameters.

4.2 Field data

The first mensurational data were obtained in 1967 in a plot of P. caribaea at Vom (planted in 1954). For every measurement, usually at two to four years interval for each plot, diameters of all trees (at breast height) greater or equal to 4 cm were measured and recorded; heights of all trees were also measured when number of trees per plot was equal to 40 or less. Where the number of trees per plot was greater than 40, thirty trees selected systematically according to the sample plot procedure by Horne(1952) and the largest 100 trees per hectare were measured for height using a Haga altimeter.

Nine to fifteen out of the sample trees measured for height were measured for volumes by sections as described by Horne (loc. cit.), at 4-yearly interval. Measurements have been expressed in metric units although initial measurements were in imperial units.

4.2.1 Plot sizes, distribution and espacement

Plot size varied from 0.0120 ha (e.g. 12m by 10m) for those plots located in species growth trials to 0.110 ha (36m by 30.5m) for those located in plantation trials and minimum initial number of trees per plot was 36 . Table 4.2.1 shows the distribution of the sample plots according to location and species. Espacement varied from 2.3m by 1.1m to 5.4m by 5.4m, but as pointed out earlier, the most commonly adopted spacing was 2.7m by 2.7m

4.2.2 Age range of trees covered by data collection

For E. tereticornis and E. cloeziana, data collection covered the ages of 4 to about 16 years

while *P. caribaea* data extended over the age range of 3 - 29 years. Table 4.2.2 shows the classification of the sample plots by age classes of stands and also by species .

Table 4.2.1 Distribution of sample plots* by locations and species

Location	Species			Total
	<i>E. tereticornis</i>	<i>E. cloeziana</i>	<i>P. caribaea</i>	
Kabama (Zaria)	3	-	-	3
Afaka	3	4	33	40
Nimbia	-	-	7	7
Miango	-	-	1	1
Ta-Hoss	-	-	1	1
Vom	-	-	1	1
Total	6	4	43	53

* Other plots with less than three sets of measurements, though considered in some of the analyses, were not included in this table.

Table 4.2.2

Classification of sample plots* by age classes and species.

Age Classes	Species			Total
	<i>E. cloeziana</i>	<i>E. tereticornis</i>	<i>P. caribaea</i>	
2 - 4	-	-	12	12
4 - 6	4	6	14	24
6 - 8	4	6	27	37
8 - 10	4	6	35	45
10 - 12	2	4	27	33
12 - 14	2	4	44	50
14 - 16	2	4	15	21
16 - 18	-	-	8	8
18 - 20	-	-	1	1
20 - 22	-	-	1	1
26 - 28	-	-	1	1
28 - 30	-	-	1	1

* Refers to number of plots with data at age classes indicated. (Other plots with less than three measurements were not included).

4.2.3 Observed stand attributes and site factors

Various measurable growth parameters and site factors were observed for possible inclusion as independent variables in the prediction of the Weibull parameters from stand/site characteristics.

The stand parameters and site factors measured include:

- i) Age (A) This is defined as the period between the time of planting up to the time of measurement, and for accuracy it was usually recorded up to the nearest decimal point of a year.
- ii) Arithmetic mean diameter (MD). This is the mean diameter per tree.
- iii) Quadratic mean diameter (D_q) This is defined as the diameter of the tree having the average basal area in the stand.
- iv) Mean diameter of dominant trees (D_d). This is the mean diameter of the largest 100 trees per hectare .
- v) Largest tree diameter in the stand (D_{mx}).
- vi) Smallest tree diameter in the stand (D_{mD}).
- vii) Number of standing trees/ha (N).

- (viii) Average relative growing space per tree as the stand ages (GSF). This is defined as the ratio of the number of standing trees at establishment or first measurement to the number of trees at the subsequent measurements. This only applied to P. caribaea which showed a great variation in stocking with age.
- (ix) Basal area (in m^2/ha) of standing trees (BA).
- (x) Top height in meters (H_d). This is defined as the mean height of the largest 100 trees/ha.
- (xi) Top height/age relationships, SIF1 and SIF2 which are defined as:
- $$SIF1 = \frac{\text{Top height}}{\text{Age}} \quad \text{and} \quad SIF2 = \frac{\text{Top height}}{\text{Age}^2}$$
- (xii) Annual rainfall in mm (RF)
- (xiii) Length of rainy days per year (RD). This is regarded as the period between the date when an accumulated total of 50 mm of rainfall has been reached and the date after which < 50 mm is expected to fall (Walter, 1967).

- (xiv) Altitude in meters (T). This is the elevation at which the stand was located above the sea level.
- (xv) Average soil depth (SD) in each plot or stand. This is regarded as the thickness of the soil (in cm) down to the lateritic hard-pan called the plinthite layer, often very common in the savanna areas of Northern Nigeria.

4.2.4 Range of stand data and type of statistics computed for each plot.

Several areas of research were covered in this thesis. While the details about the data used for the various aspects of the study can be found in the Appendices, Table 4.2.4(a) presents the summaries of the range of stand experimental data for the three species covered, namely, E. cloeziana, E. tereticornis and P. caribaea.

More-over, for each plot involved in the determination of the Weibull parameters, Table 4.2.4(b) presents the usual statistics computed.

Table 4.2.4 (a) Summary of range of stand data

	<i>E. cloeziana</i>		<i>E. tereticornis</i>		<i>P. caribaea</i>	
	Min. 1)	Max. 2)	Min.	Max.	Min.	Max.
Age (years)	4.2	15.5	3.7	14.5	3.7	29.0
Diam. (cm)	4.0	33.1	4.0	36.9	4.0	43.9
Mean diam. (cm)	10.9	24.8	11.2	23.3	11.0	40.0
Quadratic mean diam. (cm)	11.5	25.2	11.5	23.5	11.3	40.9
Mean diam. dominant (cm)	15.2	30.7	15.2	27.7	15.9	43.4
Mean height (m)	12.2	27.3	13.0	25.7	5.6	26.8
Top height (m)	14.6	28.7	15.3	27.4	8.7	28.0
Standing stems/ha	516.0	944.0	416.0	1247.0	728.0	3281.0
Standing B.A. (m ² /ha)	9.7	28.1	7.9	29.7	9.7	87.6
Total B.A. (m ² /ha)*	10.4	33.0	9.6	32.2	9.7	109.2
Standing volume (m ³ /ha)**	40.1	265.0	35.0	232.3	31.6	689.1
Total volume (m ³ /ha)**	40.1	291.6	35.0	248.6	31.6	829.2

1) Refers to minimum value

2) Refers to maximum value

* Basal area of standing trees plus basal area of thinnings

** Computations of standing and total volumes are described in Section 5.4

Table 4.2.4(b) The type of usual statistics computed for each plot*

Age (years)	4.30	6.30	7.30	9.25	12.50
Mean diam. (cm)	10.35	14.44	15.32	18.99	21.68
S. deviation ⁽¹⁾	2.45	2.03	2.29	2.34	2.90
Skewness	- 0.44	0.09	0.21	1.35	1.70
Max. diam. (cm)	15.90	19.70	22.60	28.30	34.00
Min. diam. (cm)	4.00	10.20	10.50	14.90	17.50
Kurtosis	2.75	2.77	3.34	6.50	8.01
S.E.M. ⁽²⁾	0.22	0.23	0.26	0.34	0.43
Stems/plot	128.00	77.00	77.00	45.00	45.00
Stems/ha	1185.00	713.00	713.00	417.00	417.00
B.A. (m ² /ha)	9.96	11.91	13.43	11.99	15.66

* Data from one plot of *E. tereticornis* at Kabama (Zaria)

(1) Standard deviation in diameters.

(2) Standard error of mean.

4.3 Data screening

In order to check the diameter figures for normal distribution, values of coefficient of skewness and kurtosis were determined for each plot. For most of the plots, the values of coefficient of skewness were between - 1 and + 1 ; actually, in most cases, the values were close to zero (see Tables 4.3a - 4.3c). Similarly, the values of coefficient of kurtosis were between 2 and 3, most of the values being close to 3. This means that the stem diameters in the stands had normal distribution, and hence normal testing statistics such as F-test, t-test, K-S test etc can be used to find out significant differences between the stand parameter estimates and the observed values. In a few cases where the values of skewness were much greater than 1 and the values of kurtosis much higher than 3 as in two of the plots of E. tereticornis at Kabama (Table 4.3b), this has been due to a fairly heavy thinning. This is further confirmed by the fact that the unthinned plot of E. tereticornis (Plot 2) in the same area has

relatively low values of skewness and kurtosis for the corresponding ages. For the different grades of thinnings in even-aged stands of P. radiata discussed by Jacobs (1962), Carron (1964) has shown that the d.b.h distributions of the stands before thinning, the thinnings and the stands after thinning were sufficiently normal for the application of normal testing statistics.

The apparent irregularity caused, in some cases, by lower stocking at the first measurement compared with the subsequent ones is due to the effect of measurable minimum diameter of 4 cm. In such cases, during the first measurement, trees having diameters less than 4 cm were regarded as "undergirth" and not recorded. However, during subsequent measurements, the diameters of those trees were recorded once they exceeded 4 cm.

The data from the other stand variables such as top height, basal areas of standing trees, basal areas and volumes of thinnings etc were also scrutinised and found in order before being considered for processing.

Table 4.3a Data summary for *E. cloeziana* showing the values of skewness and kurtosis at various ages and stocking.

	Age (Yrs)	Stems per ha	MnD (cm)	Dd (cm)	Dmx (cm)	Coefficient of skewness	Coefficient of kurtosis
PLANT 67	4.2	1006	4.0	11.1	17.4	- 0.39	2.23
PLOT 1	5.6	782	4.8	14.6	22.6	- 0.51	2.82
	8.2	765	5.7	17.6	26.4	- 0.59	2.73
	10.5	724	7.0	19.5	28.3	- 0.59	2.63
	12.5	557	13.4	23.0	30.6	- 0.17	2.40
	15.5	515	15.0	24.8	33.1	- 0.20	2.25
PLANT 67							
PLOT 2	4.2	1098	4.4	10.9	17.9	- 0.10	1.96
	5.6	799	6.4	14.5	21.3	- 0.44	2.36
	8.2	799	6.6	17.6	26.7	- 0.38	2.34
	10.5	790	6.6	19.2	29.0	- 0.35	2.28
	12.5	591	14.0	22.9	31.2	- 0.13	2.33
15.5	582	14.0	24.4	33.1	- 0.17	2.48	
PLANT 73							
PLOT 1	4.7	922	4.1	11.9	19.1	- 0.39	2.39
	6.5	884	4.4	14.9	24.2	- 0.47	2.44
	8.5	712	5.4	18.1	28.3	- 0.54	3.25
PLANT 73							
PLOT 2	4.7	927	4.0	11.3	18.8	- 0.30	2.02
	6.5	900	4.0	14.3	25.1	- 0.23	2.07
	8.5	756	5.7	17.2	28.3	- 0.40	2.24

Table 4.3b Data summary for E. tereticornis showing the values of skewness and kurtosis at various ages and stocking.

	Age (Yrs)	Stems per ha	MnD (cm)	Dd (cm)	Dmx (cm)	Coefficient of skewness	Coefficient of kurtosis
KABAMA	4.30	1176	4.0	10.0	15.9	- 0.70	3.07
PLOT 1	6.30	713	10.2	14.4	19.7	0.09	2.77
	7.30	713	10.5	15.3	22.6	0.21	3.34
	9.25	417	14.9	19.0	28.3	1.35	6.50
	12.50	417	17.5	21.7	34.0	1.70	8.01
	14.50	417	18.5	23.3	36.9	1.66	7.71
KABAMA							
PLOT 2	4.30	1231	4.0	10.0	15.0	- 0.68	2.59
	6.30	1185	4.0	11.9	17.8	- 0.57	2.40
	7.30	1185	4.1	12.7	19.4	- 0.49	2.36
	9.25	1176	5.1	13.9	22.3	- 0.36	2.37
	12.50	1167	5.4	15.5	25.4	- 0.30	2.44
	14.50	1148	6.0	16.1	26.7	- 0.13	2.40
KABAMA							
PLOT 3	4.30	1176	4.4	10.1	16.1	- 0.29	3.49
	6.30	528	9.5	14.2	17.8	- 0.54	2.96
	7.30	528	10.2	15.2	19.4	- 0.44	2.94
	9.25	296	14.0	18.2	22.9	0.17	3.52
	12.50	296	15.3	20.4	26.7	0.19	4.47
	14.50	296	15.3	21.3	28.3	0.14	4.50
AFAKA							
SGT 67	3.70	1183	4.6	10.3	16.6	- 0.34	3.02
	4.70	1063	4.8	12.2	18.8	- 0.18	3.43
	7.10	1053	4.8	14.4	23.2	- 0.10	3.23
	10.50	1045	6.0	16.2	28.6	0.14	2.92
	12.60	795	11.8	18.7	31.8	0.72	3.23
	14.50	795	11.8	19.8	34.0	0.69	3.11
AFAKA							
PLT 74	4.00	976	4.1	11.2	16.2	- 0.56	2.94
	6.20	976	4.1	13.6	19.4	- 0.67	2.91
	8.20	976	4.8	14.6	20.7	- 0.63	2.97

Table 4.3c Data summary for some of the *P. caribaea* plots showing the values of skewness and kurtosis at various ages and stocking.

	Age (Yrs)	Stems per	MnD (cm)	Dd (cm)	Dmx (cm)	Coefficient of skewness	Coefficient of kurtosis
AFAKA	5.7	3178	4.5	8.8	14.2	0.25	2.19
AFS 1A	9.7	3280	4.8	11.6	16.5	- 0.25	2.65
	12.2	3280	5.4	13.1	18.8	- 0.10	2.35
	14.0	3247	5.4	13.7	19.7	- 0.10	2.33
AFAKA							
AFS 1C	5.7	3418	4.0	8.8	14.9	0.26	2.72
	9.7	3418	6.0	11.9	18.8	- 0.20	2.73
	12.2	1948	8.9	15.6	23.2	0.18	3.32
	14.0	1948	9.5	16.4	24.5	0.19	3.15
AFAKA							
AFS 2D	5.7	2030	4.3	9.0	13.8	- 0.43	3.25
	9.7	2030	7.0	13.1	20.4	0.03	3.14
	12.2	1952	8.3	15.2	23.9	0.21	3.17
	14.0	1952	8.6	15.8	24.8	0.23	3.10
MIANGO							
PLANT 61	4.7	1604	4.0	9.0	13.3	- 0.25	2.44
	5.8	1662	4.8	11.0	16.2	- 0.34	2.52
	6.5	1662	5.9	12.4	18.5	- 0.28	2.50
	9.5	1662	6.7	16.3	24.7	- 0.29	2.63
	10.5	1045	10.2	19.1	26.7	- 0.17	2.74
	18.2	1045	12.7	24.9	35.0	- 0.17	2.55
	20.1	817	18.4	27.5	36.3	0.06	2.20
NIMBIA							
PLANT 68	6.2	961	4.8	10.5	19.4	0.24	2.06
	8.4	989	5.4	14.2	24.5	0.12	2.39
	10.3	961	6.4	17.0	28.0	0.00	2.39
	12.7	896	9.2	18.9	29.6	0.06	2.47
NIMBIA							
PLANT 65	6.7	1827	5.4	8.2	12.2	0.43	2.57
PLOT 1	10.9	1412	8.6	12.5	15.6	- 0.47	2.30
	13.8	1412	8.9	14.4	18.4	- 0.48	2.21
	15.7	914	13.7	17.3	20.4	- 0.28	2.94
NIMBIA							
PLANT 65	6.7	1661	5.1	9.4	12.7	- 0.09	2.01
PLOT 4	10.9	1412	9.9	12.9	18.8	0.82	2.40
	13.8	1412	10.4	14.7	23.9	0.86	3.06
	15.7	831	14.3	18.5	26.7	1.19	3.59

4.4 Data for prediction models

For orderly presentation and easy references, the description of the data for the different prediction models has been taken together in this section, but as the different models require different sets of variable inputs, the data for each prediction model will be discussed separately.

4.4.1 Data for Weibull distribution

For the determination of the Weibull parameters, E. cloeziana had diameter data from 4 plots which were all located at Afaka. E. tereticornis had data from 3 plots at Kabama and another 3 from Afaka. P. caribaea had data from 17 plots at Afaka, 7 plots from Nimbia, 1 plot at Vom and 1 plot at Miango. All these plots had been measured at various ages and the stand parameters calculated at each measurement formed a set of data.

The data for the construction of the Weibull parameter predictive models consisted of the determined Weibull parameters (that gave a good fitting

to diameter distribution of plot data) at each measurement and the observed stand attributes and site factors listed in Section 4.4 . However, for some of the species, some site factors (e.g. rainfall, altitude, soil depth etc) which were constant or the same over the areas covered were not included. E. cloeziana, E. tereticornis and P. caribaea had 18, 23 and 80 sets of data respectively (Appendices 7(a - c)).

4.4.2 Data for top height-age curves.

E. cloeziana had 22 sets of height-age data (Appendix 8(a)), 18 of which were extracted from Appendix 7(a) while the remaining 4 were from stands not included in the data for the Weibull parameter predictive models. The data for E. tereticornis included 35 sets of observations (Appendix 8(b)), 23 of which were extracted from Appendix 7(b) and the remaining 12 were from new stands. P. caribaea had 201 sets of observations (Appendix 8(c)), 80 of which were extracted from Appendix 7(c).

4.4.3 Data for volume prediction

For each species, both the data for the development of the stand volume model and the construction of the total volume production-age models were in the same data file and were therefore printed together. There were 15 sets of data for E. cloeziana (Appendix 9(a)), 32 sets for E. tereticornis (Appendix 9(b)) and 54 sets for P. caribaea (Appendix 9(c)). During the development of the total volume production - age models, the only additional work required was to extract the sets of the volume - age data for the determination of the parameters for the non-linear models.

CHAPTER 5

MODEL SELECTION AND FITTING PROCEDURES

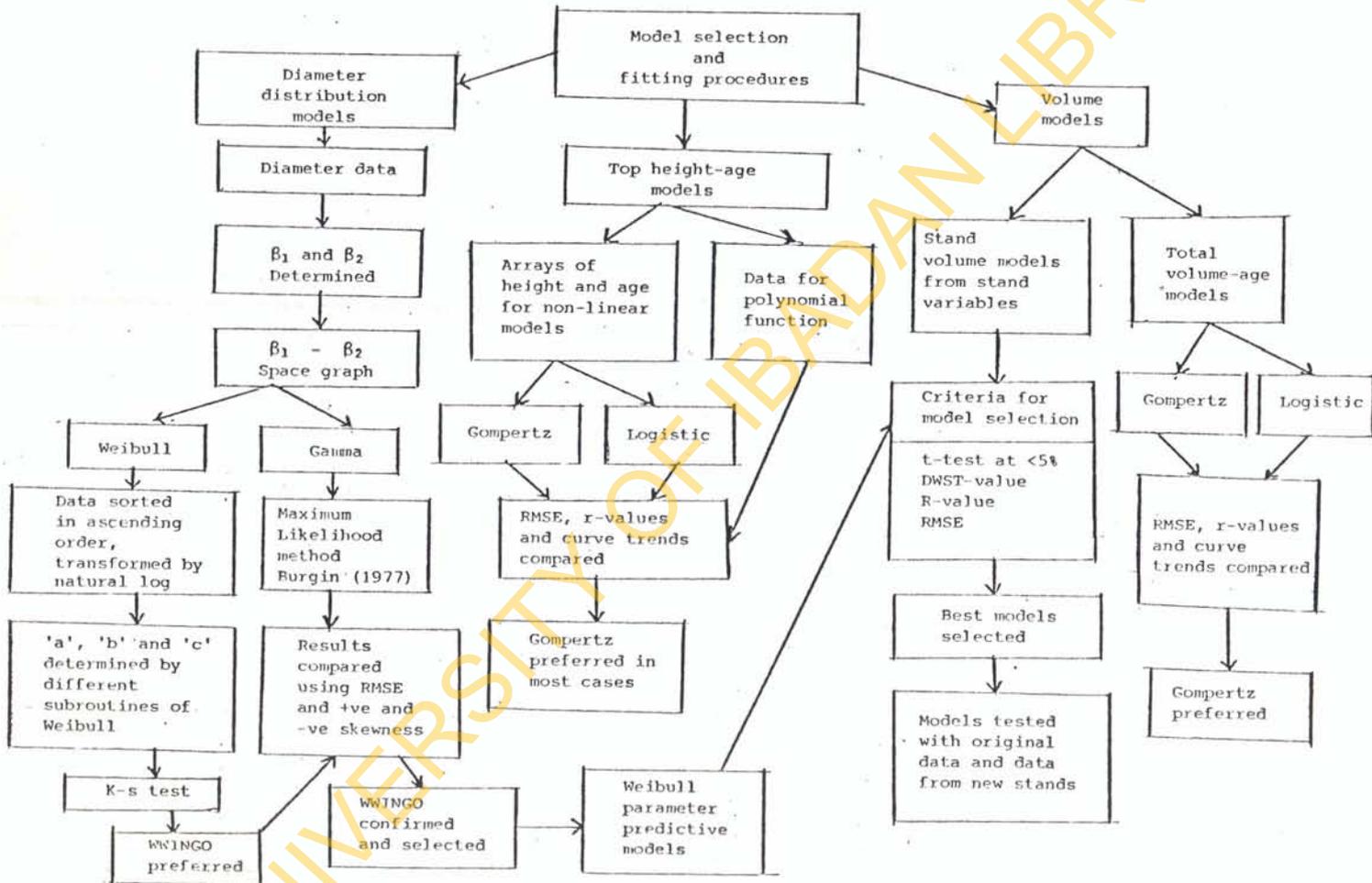
5.1 Flow-chart for model selection and fitting procedures.

Several areas of research were covered in this study and these include:

- (a) The Weibull function for describing diameter distribution and prediction of the Weibull parameters from the stand attributes and site factors.
- (b) Fitting of the average top height-age curve (i.e. site index curve for the average site) for each of the species.
- (c) Development of stand volume model and fitting of the average total volume production-age curve for each species.

Therefore, in order to facilitate the descriptions of the data analyses, a flow-chart for model selection and fitting procedures that covered all these sub-topics has been drawn up (see Fig.5.1) .

Fig. 5.1 Flow-chart for model selection and fitting procedures



5.2 Procedure for diameter prediction.

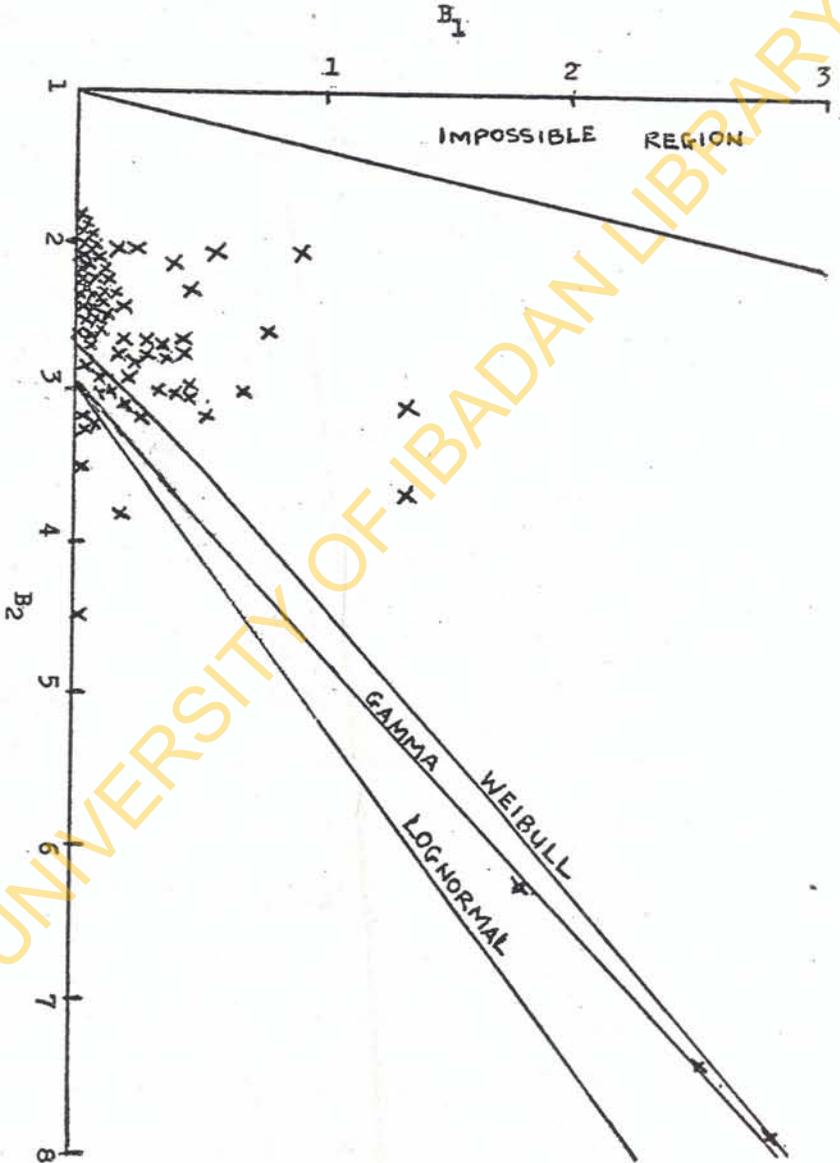
The different diameter distribution models in use have been discussed in Section 2.2.2.1. The log-normal and gamma distributions are noted for generating positively skewed curves. The Weibull distribution is capable of producing curves with skewness values varying from positive to negative. A close look at the data summaries (in Tables 4.3a - 4.3c) showing the values of skewness for some of the plot data indicates that the Weibull distribution might be most appropriate for describing the stem diameter distribution. This satisfied the condition of producing curves of positive to negative skewness which characterised most of the stands.

An alternative approach to the selection of the diameter distribution models is the plotting of values of the square of coefficient of skewness, B_1 , against the values of kurtosis, B_2 , on a $B_1 - B_2$ space graph and comparing the scattered diagram with various statistical distributions (Johnson and Kotz, 1970 ; Hafley and Schreuder, 1977). While

this method is said not to be a confirmatory criterion in selecting a suitable distribution model for a set of data, such a graph is very useful in considering the strength and weakness of the distributions. In other words, it is possible to identify the distributions that should not be selected for a particular type of data. Fig. 5.2 shows the coefficient of skewness squared (B_1) and coefficient of kurtosis (B_2) from the plots of the three species on a $B_1 - B_2$ space graph. Considering the three statistical distribution functions, viz: - the Weibull, gamma and lognormal, - the lognormal distributions seem to be the least suitable for describing the data. The plotted data are denser around the Weibull distribution area than the gamma, suggesting an advantage of the Weibull over the gamma distribution. A package of gamma distribution was also tested on some of the data and it was found that the gamma distribution was less efficient in describing the data when compared with the most suitable subroutine of the Weibull program.

Fig. 5.2

Skewness squared plotted against kurtosis of plot data on a $B_1 - B_2$ space graph and compared with existing statistical distributions (Johnson and Kotz, 1970).



(The different subroutines of the Weibull program tried are discussed later in the text).

The beta and the Johnson's S_B distributions which are also flexible (Hafley and Schreuder, 1977) may be capable of describing the data. These two distributions were not represented on the $B_1 - B_2$ space graph because of their greater coverage especially along the B_2 axis . However, their major demerits lie in the fact that calculations of their density functions to obtain diameter distributions or certain diameters at some specified percentiles require laborious efforts as a series of integrations will be involved (Bailey and Dell, 1973). Moreover, there exists the problem of relating their estimated parameters to the stand attributes (Monness, 1982; Bailey and Dell loc. cit.). The Weibull distribution has been known to overcome all these demerits. Schreuder and Swank (1974) and Rustagi (1978) found the Weibull function very efficient in describing the stand structure. The potential of the Weibull

in quantifying the structures of both even-aged and uneven-aged forests has been further re-emphasised by Schreuder et al. (1979), Campos (1981), Ung et al. (1982), Susan (1983) and Hyink and Moser (1983). Hence the selection of the Weibull distribution function for the study was considered most appropriate.

5.2.1 The Weibull program

The cumulative distribution of the 3-way parameter Weibull has been defined as

$$F(X) = 1 - \exp \left\{ - \left\{ (X-a)/b \right\}^c \right\} \quad (25)$$

where : $a < X < \infty$; $b, c > 0$

X = a random variable such as the tree diameter.

a = location parameter

b = scale parameter

c = shape parameter

e = exponential constant

For the purpose of illustration, in Fig. 5.2.1(a),

$$F(X_0) = 1 - e^{-\left(\frac{X_0 - a}{b}\right)^c} \quad (26)$$

where:

$$a < X_0 < X_1 \quad ; \quad b, c > 0$$

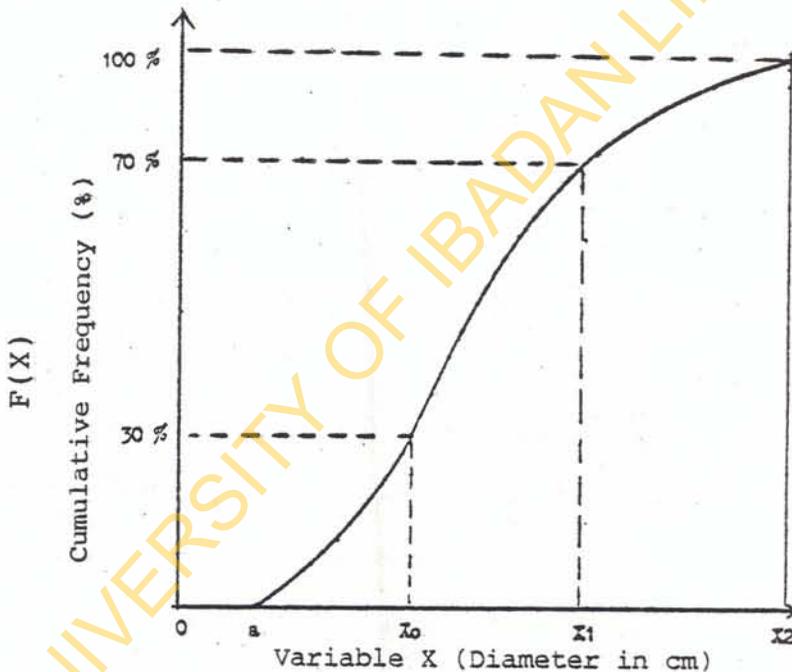


Fig. 5.2.1(a) Cumulative density of the 3-way parameter Weibull distribution.

$F(X_0)$, which is 30%, measures the cumulative frequency of trees up to diameter X_0 and is represented by the area under the curve between $X = a$ and $X = X_0$.

If $F(X_0)$ is replaced by the ratio of cumulative basal area (BX_0) of all trees up to diameter X_0 to the total stand basal (B), then the function becomes:

$$BX_0/B = 1 - e^{-\left(\frac{X_0-a}{b}\right)^c} \quad (27)$$

$$BX_0 = B \left\{ 1 - e^{-\left(\frac{X_0-a}{b}\right)^c} \right\} \quad (28)$$

Hence the cumulative basal area up to diameter X_0 can be computed.

There are also well-established relationships between the Weibull parameters for diameter distribution and Weibull parameters for basal area distribution of trees. Schreuder and Swank (1974) have proved that if the diameter (in cm) follows the Weibull distribution with the parameters 'b' and 'c', then the basal area (in cm^2) follows the Weibull distribution with the parameters b_1 and c_1 where :

$$b_1 = \pi b^2 / 4 \quad \text{and} \quad c_1 = c/2 \quad (29)$$

The proportion of the distribution lying between any two specific values of X , say X_1 and X_2 ($X_1 < X_2$) in Fig. 5.2.1(a) is defined as

$$\begin{aligned}
 P(X_1, X_2) &= F(X_2) - F(X_1) \\
 &= e^{-\left\{ \left(\frac{X_1 - a}{b} \right)^c \right\}} - e^{-\left\{ \left(\frac{X_2 - a}{b} \right)^c \right\}} \quad (30)
 \end{aligned}$$

The probability density function for the 3-way parameter Weibull distribution is given by

$$f(X_0) = \frac{c}{b} \left(\frac{X_0 - a}{b} \right)^{c-1} e^{-\left\{ \left(\frac{X_0 - a}{b} \right)^c \right\}} \quad (31)$$

where:

$$a < X_0 < X_1; \quad 0 < a < X_1 \quad b, c > 0$$

If ' c ' = 1 and ' a ' = 0 (i.e. assuming a 2-way Weibull parameter distribution), then an exponential distribution occurs

$$f(X_0) = 1/b \exp - (X_0/b) \quad (32)$$

where:

$$0 < X_0, \quad b > 0$$

If ' c ' = 2 and ' a ' = 0, the Rayleigh, a

special case of X^2 distribution occurs

$$f(X_0) = 2/b (X_0/b) \exp-(X_0/b)^2 \quad (33)$$

where:

$$X_0, b > 0.$$

The parameter 'a' marks the beginning of the point of distribution and is regarded as the location parameter. The cumulative diameters in percentages on the Y-axis corresponding to diameters X_0 and X_1 (Fig. 5.2.1(a)) are referred to as percentiles. For example, at the 70th percentile of the distribution, it is expected that 70% of all the trees are smaller than the diameter X_1 . For computation purposes, $F(X)$ is usually expressed by percentiles.

The scale parameter 'b', for example determines the peak of a distribution of an increment (or growth) curve which itself is generally measured by kurtosis or coefficient of kurtosis. Change in the shape of growth curves can occur by varying the numerical values of the scale parameter (Yang et al., 1978). Fig. 5.2.1(b) shows that at fixed values

of the shape parameter 'c', the peak of the increment curve increases in sharpness as the scale parameter 'b' decreases in value. Also, the cumulative total volume production/age curves show a similar behaviour. However, the shape parameter 'c' still dominates the shape of an increment (density) curve. It can also be concluded from Fig. 5.2.1(b) that virtually all biological growth phenomena can be modelled by the modified Weibull function with varying scale and shape parameters.

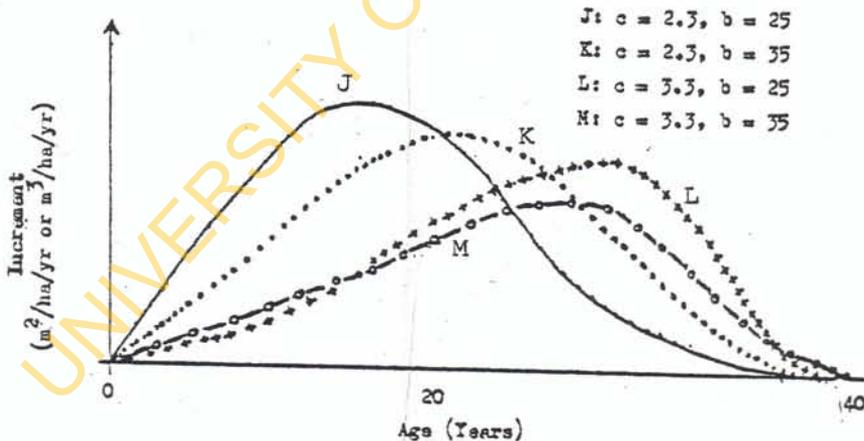


Fig. 5.2.1(b) Changes in shape of the modified Weibull increment curves at varying values of 'c' and 'b' (Yang *et al.*, 1978)

5.2.1.1 Data input programs

Data input programs written in APL (A programming Language) took care of data entry from the computer terminal. It consisted of several subroutines such as TREES, SEEDATA, COMBINE, EXTRACT etc (see Appendices 3(a-h)). SEEDATA enabled data entered to be recalled on the terminal for corrections; COMBINE compressed several data files together without merging them while EXTRACT brought out any required data file from the combined files. The subroutine, TREES, performed four options as follows:

- (i) Opening of a new data file and entering of data.
- (ii) Allowed data entry to resume from the existing temporary random access file.
- (iii) Sorted diameter figures in ascending order and arranged them in format accepted by the multi-Weibull programs (see Appendix 2(a)).
- (iv) Computed statistics from the existing file and the usual statistics for each stand or plot have been shown in Table 4.2.4(b).

5.2.1.2 Determination of the Weibull parameters.

Several methods are available for the determination of the Weibull parameters, but the choice of any particular method should depend on the computing facilities available, statistical efficiency desired and the amount of fund available for such a research undertaking. Basically, there are two approaches for estimating the Weibull parameters. One of these is the linear estimation method and the second is the maximum likelihood procedure. Generally, the methods based on the maximum likelihood procedure give better estimates of the parameters, but involve iterative computations which consume a lot of computer time and are therefore expensive (Bailey and Dell, 1973).

The general procedure involved in the estimation of the Weibull parameters, using either the linear estimation technique or the maximum likelihood method includes:

- (a) Sorting of the (Weibull) variable X in order of increasing magnitude (i.e. censored data).

- (b) Transformation of variable X and all the other links of the equation, for example, by using Napierian (natural) logarithm.
- (c) Estimation of the Weibull parameters by regression techniques.

The linear estimation method, though less efficient in terms of parameter estimation is the easiest to compute. Using this method, the Weibull parameters can be derived from Model (25) as follows:

$$\text{Ln} \left\{ \frac{1}{1 - F(X)} \right\} = \frac{(X-a)^c}{b}$$

$$\text{Ln} \left\{ \ln \left\{ \frac{1}{1 - F(X)} \right\} \right\} = c \ln(X-a) - c \ln b$$

$$\text{Let } \text{Ln} \left\{ \ln \left\{ \frac{1}{1 - F(X)} \right\} \right\} = W \quad ; \quad \ln(X-a) = T$$

$$\text{Then } W = a_1 + a_2 T \quad (34)$$

$$\text{With } a_1 = -c \ln b$$

$$a_2 = c$$

$$b = \exp(-a_1/a_2)$$

Selecting the two percentiles in Fig.5.2.1(a), viz: $F(X) = 0.30$ for $X = X_0$ and $F(X) = 0.70$ for $X = X_1$ and fixing 'a' parameter as any value less than the minimum diameter but not less than zero, two simultaneous equations will be obtained from which the values of 'b' and 'c' can be computed. The above method derived by Fulkerson (personal communication)¹ is a further simplification of the percentile method described by Bailey and Dell(1973) and is an approximate procedure for obtaining the starting values for the algorithms based on the maximum likelihood method.

Dubey (1967) showed that the 17th and the 97th sample percentiles are asymptotically the best for estimating 'c' without prior knowledge of 'b', giving 66% efficiency when compared to the maximum likelihood estimator. He also stated that the 40th and 82nd percentiles are the best for estimating 'b' for unknown 'c' with 82% efficiency.

1) Mr. L. Fulkerson is the Chief Data Analyst at the Computer Centre, Ahmadu Bello University, Zaria.

Some other researchers who have used the linear functions to estimate 'b' and 'c' include Gumbel (1958), Menon(1963),and Bain and Antle(1967). White (1969) used weighted least squares estimators that are unbiased. Mann(1967) obtained the best linear estimators close to the maximum likelihood estimators. The methods evolved by the last two authors, which are applicable to censored data, require tables of weights which must be entered for each sample size, degree of censoring, and the ranked position.

D'Agostino (1971) gave a modification of a procedure derived by Johns and Lieberman (1966). The estimators are linear functions which are asymptotically jointly normal and efficient. The weights required are functions of the proportion of available observations and the sample size. D'Agostino's estimators compare quite well with those of Mann(1967) and White (1969).

The estimation of the Weibull parameters by the maximum likelihood method has been explained by Cohen (1965). He gave the maximum likelihood equation, the estimators, variances and covariances of the

estimates for complete singly and progressively censored samples. The maximum likelihood method which involved iterative processes includes the application of probability to optimize the values of the parameters.

For the determination of the Weibull parameters for the stands covered, a package of Weibull program with multiple subroutines (multi-Weibull programs) was first tried on some of the data. The multi-Weibull programs developed by Bailey¹⁾ and written in a FORTRAN language consisted of about 1050 statements. The subroutines include:

1. DAGOS
2. WINGO
3. WWINGO
4. FITTER 1
5. FITTER 1.0
6. FITTER 2
7. FITTER 2.0
8. HARTER

1) Dr. R.L. Bailey, formerly based at Southern Forest Experimental Station, New Orleans, U.S.A, is a mathematical statistician.

Each of these subroutines performs the same function of determining the parameters. In the multi-Weibull programs, DAGOS estimates the 'b' and 'c' parameters based on simple linear regression method after being assigned the value for 'a' parameter. The value for the 'a' parameter in DAGOS should not be less than zero and should be less than the minimum diameter. This is a necessary condition in the estimation of the parameters to avoid the problems associated with logarithms of negative numbers. The remaining subroutines (2-8 listed above) are based on the maximum likelihood estimation method.

In order to execute the subroutine WINGO, the estimated values for 'c' and 'b' parameters in DAGOS were used as starting values in the iterations of the maximum likelihood algorithm at the end of which the final values for 'a' , 'b' and 'c' were obtained. The subroutine WWINGO is essentially the same as WINGO except that the former corrected the shape and scale parameters for bias for sample sizes of 5 to 120 .

The subroutine FITTER 1 used the estimated 'a', 'b' and 'c' parameters from WINGO as starting values in iterations of the maximum likelihood algorithm to obtain the final values of the Weibull parameters. FITTER 1.0 subroutine rounded up the value for 'a' parameter from WINGO to the nearest integer. FITTER 2 is essentially the same as FITTER 1 except that it corrected the shape and scale parameters for sample size bias as in WINGO. FITTER 2.0 rounded up the value for 'a' from WINGO to the nearest integer and also corrected the shape and scale parameters for bias for sample size of 5 to 120. To execute the subroutine HARTER, the values for 'a', 'b' and 'c' in FITTER 1 were used as initial values in the iterative procedure to obtain the final estimated values for the parameters. HARTER did not correct for sample size bias.

The original programs were modified to incorporate a subroutine, TEST, which tested the fitness of the approaches to the actual data. A further simplification of the results in TEST was carried out so that frequency distribution into 2 cm diameter

classes could be obtained directly per plot instead of basing calculations on Model (25) or having the distribution on per hectare basis as it was in the original programs (Appendices 1 and 2). This made it easy to find out whether the predicted diameter distribution obtained from each subroutine significantly differed from the actual diameter distribution using the Kilmogorov - Smirnov (K-S) two-sample test. The subprogram TEST also made available gamma functions (GAMMA1 and GAMMA2) and variance of the Weibull statistics and these assisted in selecting the most suitable subroutine for the analyses of the data. The smaller the gamma values and the variance, the more suitable the subroutine.

5.2.1.3 Determination of the parameters for gamma distribution.

The probability density function of gamma distribution has been given as

$$f(X) = \frac{A^B}{\Gamma(B)} X^{B-1} e^{-AX} ; A, B > 0 \quad (35)$$

The mean of a gamma distribution is defined as

$$\bar{X} = \frac{B}{A} \quad \text{and its variance } (\phi^2) = \frac{B}{A^2} \quad (36)$$

For $B = 1$, an exponential distribution occurs.

$$f(X) = A e^{-AX} \quad ; \quad A > 0 \quad (37)$$

An approximate and simple procedure for estimating gamma distribution consists of the following steps:

(i) A and B parameters of the distribution are estimated from the mean and variance of the variable (e.g. diameters of trees in a plot).

(ii) The gamma function, $\Gamma(B)$, is then obtained from a gamma function table (Appendix 10(b)) at the corresponding value of B and the probability density function is calculated using Model (35).

If X_1, X_2, \dots, X_4 are diameter class mid-points of a frequency distribution such that X_1 is lowest class mid-point, then the cumulative gamma

distribution is given by

$$F(X) = f(X_1) + f(X_2) \dots + f(X_4) \quad (38)$$

The gamma distribution is not a continuous function as the gamma function, $\Gamma(B)$, varies with the value of B .

The maximum likelihood algorithm used for estimating the gamma distribution in some of analyses was developed by Burgin (1977) and Appendix 6 shows the listing of the program. The original program, based on a 2-way parameter distribution, was adjusted to include a location parameter having a value close to the 'a' parameter of the best subroutine of the multi-Weibull programs selected. This was to enable the fitting from the gamma to be compared with the fitting from the best subroutine of the multi-Weibull programs.

5.2.1.4 Preliminary analyses for Weibull distribution trial fittings

The first trial run involved diameter data from a stand of E. tereticornis at Kabama (Zaria)

at ages 4.3, 6.3, 7.3, 9.25 and 12.5 years. The value for 'a' parameter in DAGOS was fixed at 0.0 . During the second run, the value for 'a' was fixed as 0.999 times the minimum diameter ($0.999 \times \text{MnD}$) which of course represents its maximum value (Alder, personal communication¹).

The next set of trial runs involved diameter data from a stand of P. caribaea at Afaka at ages 5.7, 9.7, 12.2 and 14 years with the initial values of the location parameter in DAGOS first set as 0.0 and then as $0.999 \times \text{MnD}$. In both trial runs, the results of the preliminary analyses which will be discussed later were encouraging. This therefore led to the next stage which was the selection of the most suitable subroutine for determination of the Weibull parameters.

It was possible to obtain the frequency distribution of the number of trees per plot in 2 cm diameter classes under the sub-program, TEST, incorporated into each subroutine and hence the cumulative

1) Dr. D. Alder, formerly based at Takoradi, Ghana, is an F.A.O./U.N.D.P Forestry Expert.

frequency distribution (c.f.d) for each plot at every measurement could be obtained. Moreover, using 2 cm diameter classes, the c.f.d based on the actual plot data was obtained. It was therefore desirable to apply the Kilmogorov-Smirnov (K-S) two-sample test to find out if there was a significant difference between the diameter distribution predicted by each subroutine and the distribution based on the actual data. (The procedure for carrying out the K-S test can be found in Appendix 5). For E. tereticornis, the c.f.d from all the subroutines (listed in Section 5.2.1.2) showed a significant difference from the c.f.d of the actual data at age 4.3 years. However, while the c.f.d from DAGOS showed a significant difference from the c.f.d of the actual data up to the age of 7.3 years, the c.f.d from the subroutines based on the maximum likelihood method did not show any significant difference as from the age of 6.3 years. With regard to P. caribaea, while the c.f.d from DAGOS showed a significant difference from the c.f.d of the actual data for ages of 5.7 and 9.7 years, the

c.f.d from the subroutines based on the maximum likelihood method did not show any significant difference for all ages of measurement (i.e. 5.7 - 14 years).

Based on these facts, it was concluded that while the DAGOS subroutine would not be appropriate for the determination of the Weibull parameters in most of the stands, any of the subroutines based on the maximum likelihood algorithm could be used. The WWINGO subroutine appeared to be the most suitable as it had a comparatively shorter execution time and corrected for sample size bias for observations between 5 and 120.

From Fig.5.2, the $B_1 - B_2$ space graph, apart from the Weibull distribution, the gamma distribution was the next model that might as well describe the data. Before the selection of the most suitable subroutine was finalised, the c.f.d from the WWINGO was compared with the c.f.d from the gamma distribution based on the diameter data of the three species at Afaka. The WWINGO still proved superior and hence it was selected.

The value of 'a' parameter selected as a starting point in DAGOS (from which the WWINGO obtained the starting values of 'b' and 'c') was fixed as $0.999 \times \text{MnD}$. The diameter data of E. tereticornis at Kabama at age 4.3 years were deleted and not considered for further analyses.

Further analyses which followed the selection of the best subroutine were the determination of the Weibull parameters and fitting of the Weibull distribution to more plot data of E. cloeziana, E. tereticornis and P. caribaea . After this, the Weibull distribution was fitted to the pooled diameter data of each of the three species (i.e all diameter data of each species analysed together irrespective of age and site differences).

5.2.1.5 Procedure for Weibull parameter predictive models

The Weibull parameters have been determined for the various stands of the three species at the different localities based on the WWINGO subroutine.

For each set of data analysed for Weibull parameters, the goodness of fit of the distribution was carried out using the K-S test(mentioned in Section 5.2.1.4). Some of the early measurements from some of the species were found not to fit into the Weibull distribution and hence such data were not included in the construction of the general prediction models. For E. tereticornis, only data collected as from ages of 6.3 and 4 years at Kabama and Afaka respectively were considered for the general models. With regard to E. cloeziana, only data collected as from the age of 4.2 years were considered. P. caribaea data included only those collected as from the age of 6.5 years at Miango and as from the age of 5.7 years at both Afaka and Nimbia. These minimum age limits will later assist in determining for each species the minimum age for which the general models would be regarded as efficient for prediction purposes.

The various stand attributes and site factors (listed in Section 4.2.3) that are likely to affect tree growth and diameter distribution were measured.

Therefore, all the data from each species and from the various locations were considered together for the determination of the composite models. Details about the data for the Weibull parameter predictive models have been given in Section 4.6 . Appendices 7(a), 7(b) and 7(c) show for E. cloeziana, E. tereticornis and P. caribaea, respectively, the determined Weibull parameters, the stand attributes and the measurable site factors. The prediction process will be completed by describing two more important steps, viz: procedure for selecting the most appropriate models and the prediction approach of the Weibull parameters for the species.

- (a) Procedure for selecting the most appropriate models.

In this type of search-for-the best model exercise, except there are well laid down criteria, one may sometimes be confused as to which model to select especially when there are many alternatives. The regression package used was an APL Statistical Inquiry Package (ASIP), which provided among other things, the coefficient of multiple correlation (R) and the Durbin-Watson Statistic (DWST) for each regression

model. In addition, it provided the t-value and the significance level for each of the explanatory variables. In this way, it was possible to drop out any of the insignificant independent variables from the models. More variables likely to be significant and at the same time increase the R-value and the DWST-value were then included in the models (i.e. using a step-wise regression procedure).

The DWST-value itself generally gives an indication of the predictive strength of a model. A model with a fairly high R-value but relatively low DWST-value (compared with the value in Appendix 10(a)) is rarely good for prediction. In fact, this indicates that the R-value for such a model might have been over-estimated or that the residuals (the observed minus the predicted values) from the regression model might be correlated, a case of serial correlation (Johnston, 1963).

For each of the selected models therefore, each of the explanatory variables was significant at least up to 5% level. The minimum R-value for any of the models was not less than 0.85 and the DWST-value was not less than the recommended lowest limit (d_L) at 5% significance level in Appendix 10(a).

- (b) Prediction approach of the Weibull parameters for the species.

The first step was to determine the correlation matrix for each of the species. This gave an indication of which variables the Weibull parameters were highly correlated with, and hence a good starting point.

For both E. cloeziana and E. tereticornis, development of the Weibull parameter predictive models based on all the data as from the minimum age limits stated in Section 5.2.1.4 did not present much problem. However, with regard to P. caribaea, reliable models could not be obtained when all the data (as from the minimum age of 5.7 years) were used. Therefore, the data from the younger stands were deleted gradually until the minimum age of 8.4 years when the best models were obtained. This reduced the original 108 sets of data to 80 left in Appendix 7(c). The prediction process of the parameters for P. caribaea was also more complicated than those of the other two species because the correlations of the Weibull parameters with the stand attributes and site factors were relatively

low. However, the Weibull parameters were highly correlated with each other and the 'a' parameter was highly correlated with some of the stand attributes. For this reason, 'a' was first predicted from the stand attributes. Then 'c' was predicted from the predicted 'a' and some stand attributes. Finally, the 'b' parameter was predicted from the predicted 'c' and the predicted 'a' and some other variables.

5.3 Model fittings for top height-age data.

The top height-age data for each of the species (Section 4.5.2) were first plotted (Figs.5.3(a - c)) before curves representing the average site classes were fitted using the three functions, viz: the Gompertz, the Logistic and the polynomial functions. The parameters for the Gompertz and the Logistic models were estimated based on the non-linear least square method using the iterative procedure (Marquardt, 1963).

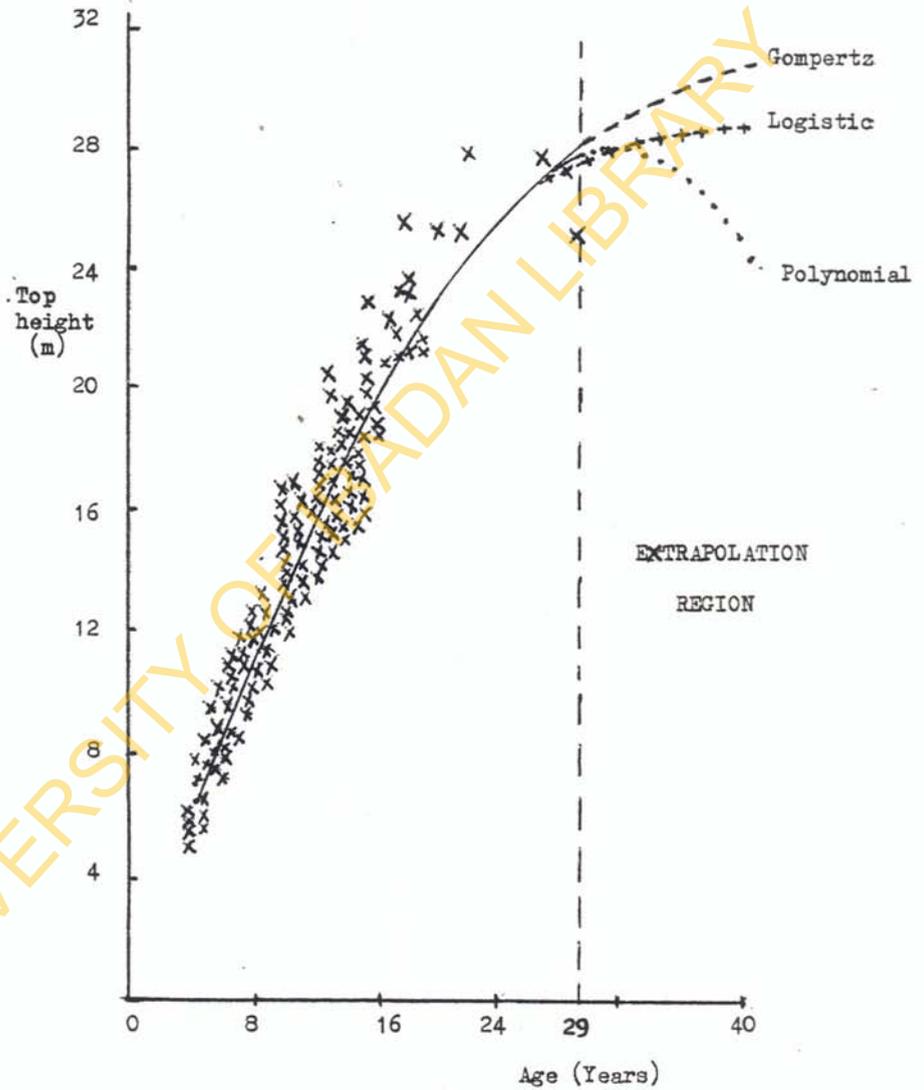


Fig. 5.3(c)

Fitting of the average site
index curve for *P. caribaea*

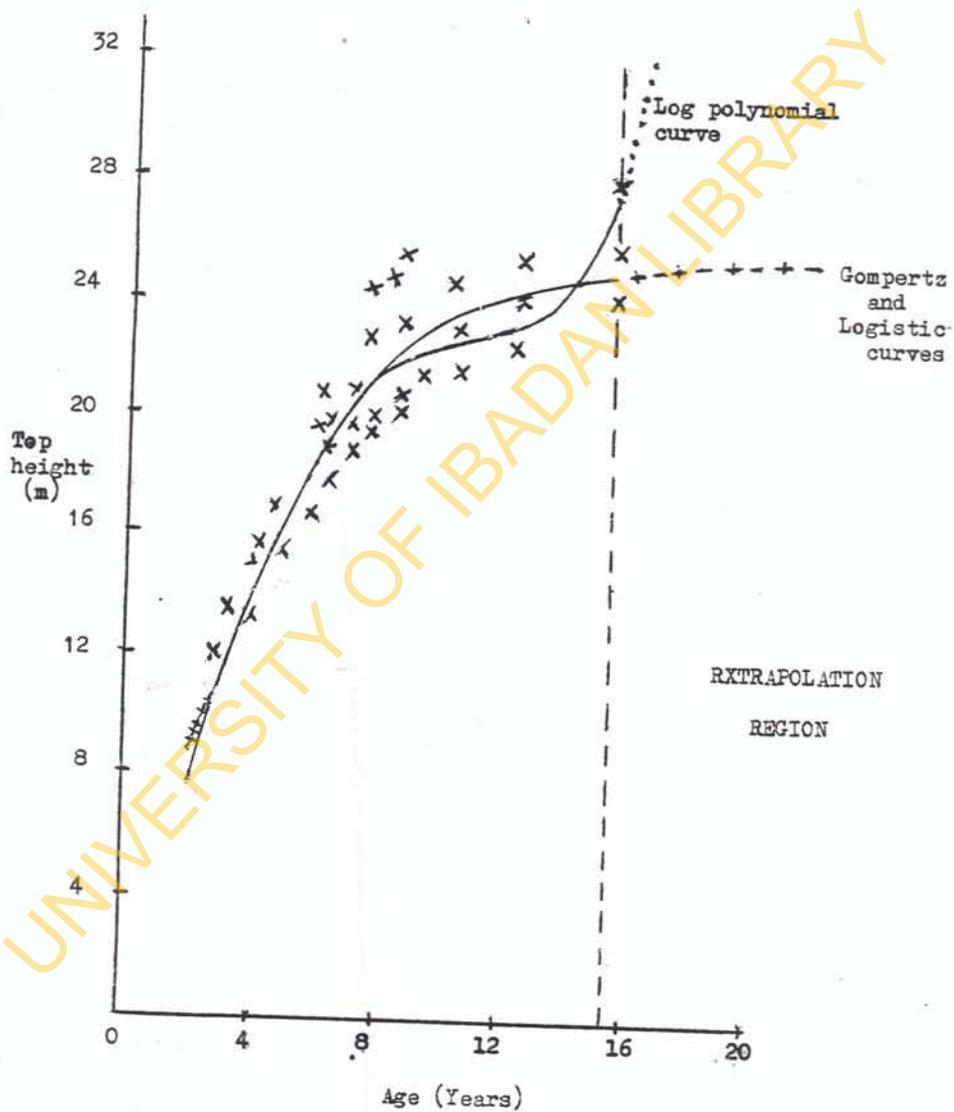


Fig. 5.3 (b) Fitting of the average site index curve for E. tereticornis

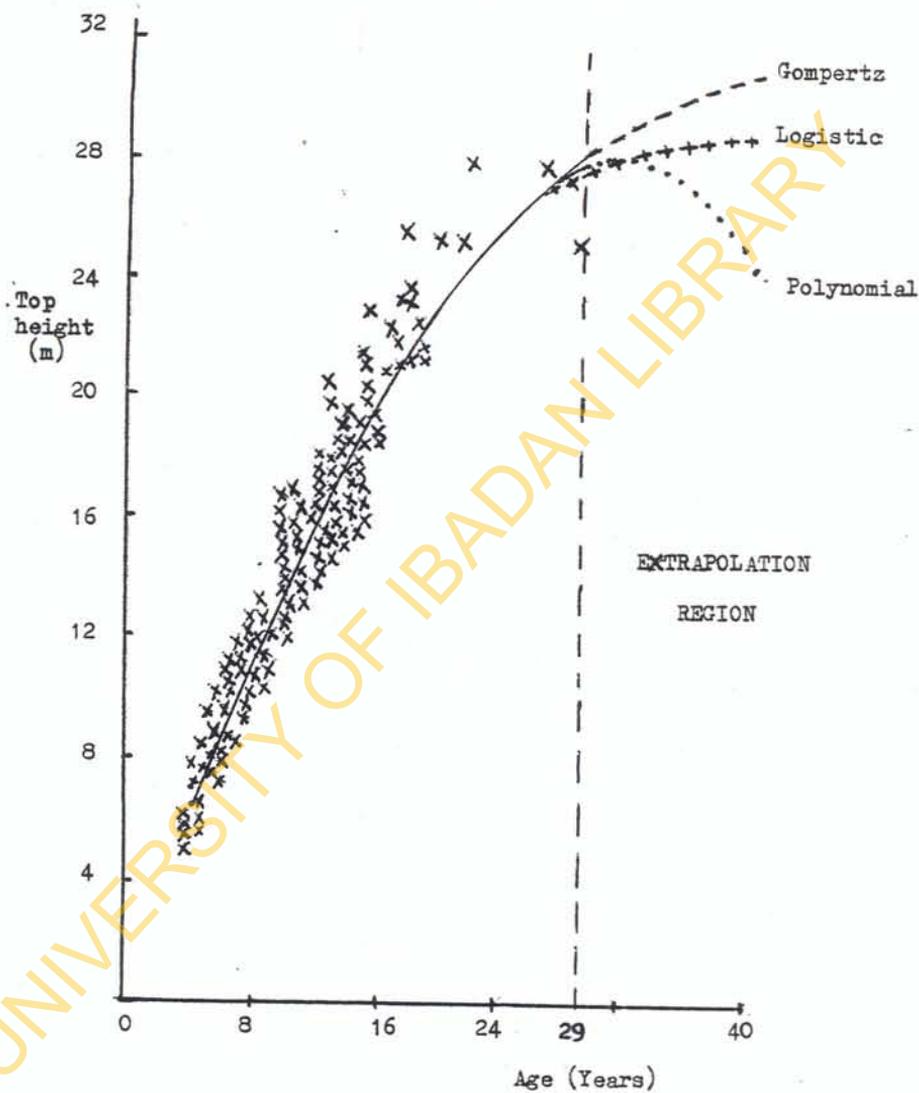


Fig. 5.3(c)

Fitting of the average site index curve for P. caribaea

5.4 Procedure for volume prediction

The first stage in the procedure for volume prediction involved the calculations of standing and total volumes from the plots.

As earlier mentioned in Section 4.2, volumes of sample trees are usually measured at 4-year intervals but this intensive study made it compulsory for some of the plots to be measured for volumes at 2-year intervals. Volume measurements followed the procedure described by Horne (1952). Normally, 9 - 15 sample trees per plot are measured for volumes depending on the plot size. Each sample tree is measured in 1.5 - 4.5 m log sections up to a timber height of 7.5 cm diameter top (usually by climbing with a ladder). The most common length of sections was however 3m. The volume of each sample tree is then calculated by sections using the Huber's formula (Carron, 1968). From the volumes of sample trees and their basal areas at breast height, a volume-basal area line equation (Carron, loc. cit.) would be established. The standing volume per ha in records at Samaru used to be computed based on the mean tree method using the volume - basal area functions.

The mean tree method of estimating standing volumes however has the tendency to over-estimate standing volumes. Therefore, considering the various ages and stocking for each of the species, some of the plot measurements were selected and their standing volumes were re-calculated using the diameter-grouping method with 4 cm class interval. The new standing volumes obtained and the previously computed standing volumes then served as correction factors for all the previously computed standing volumes in all other stands of similar characteristics. Where some of the plots had been thinned, the cumulative thinning volumes added to the corrected standing volume gave the total volume production. Similarly, the total basal area production at each age was obtained by adding the cumulative thinned basal area to the standing basal area. The data involved in volume prediction for each of the species were already discussed in Section 4.5.3 and can be found in Appendices 9(a - c).

5.4.1 Procedure for stand volume models.

As in the case of predicting the Weibull parameters from the stand attributes and site factors, the first step was to determine the correlation matrix for each of the species and then have an idea about the easily measured variables that were highly correlated with the standing volume. This served as a useful starting point. Next, the procedure for selecting the most appropriate model explained in Section 5.2.1.5 was adhered to until the best stand volume model was obtained for each species.

5.4.2 Model fittings for total volume-age data.

The data of total volume production/age (Appendices 9(a - c)) were first plotted for each of the species (Figs.5.4.2(a - b) and Fig.5.4.2.1). From the plottings, a first guess of the trends of the curves was obtained and this gave an indication of the type of models to be tried. The Gompertz and Logistic models were then fitted to the data of each of the species.

Traditionally, the practice is first of all to obtain a relationship between top height and age

(or construct a site index curve). Next, another relationship between the total volume production and top height is obtained before the relationship between the total volume production and age is finally obtained (Kingston, 1970; Omiyale and Joyce, 1982). In the case of E. cloeziana and E. tereticornis, this long process was not necessary since the total volume production was more directly correlated with age than with the top height (Table 5.4.2) whereas for P. caribaea the total volume production was more correlated with top height than age.

Table 5.4.2 Correlations of the total volume production with age and top height for the under-mentioned species.

	<u>E. cloeziana</u>		<u>E. tereticornis</u>		<u>P. caribaea</u>	
	TV*	Age	TV	Age	TV	Age
Age (Yrs.)	0.989	-	0.941		0.705	-
H _d ** (m)	0.961	0.944	0.817	0.890	0.733	0.930

* Refers to total volume production (m³/ha).

** Refers to top height.

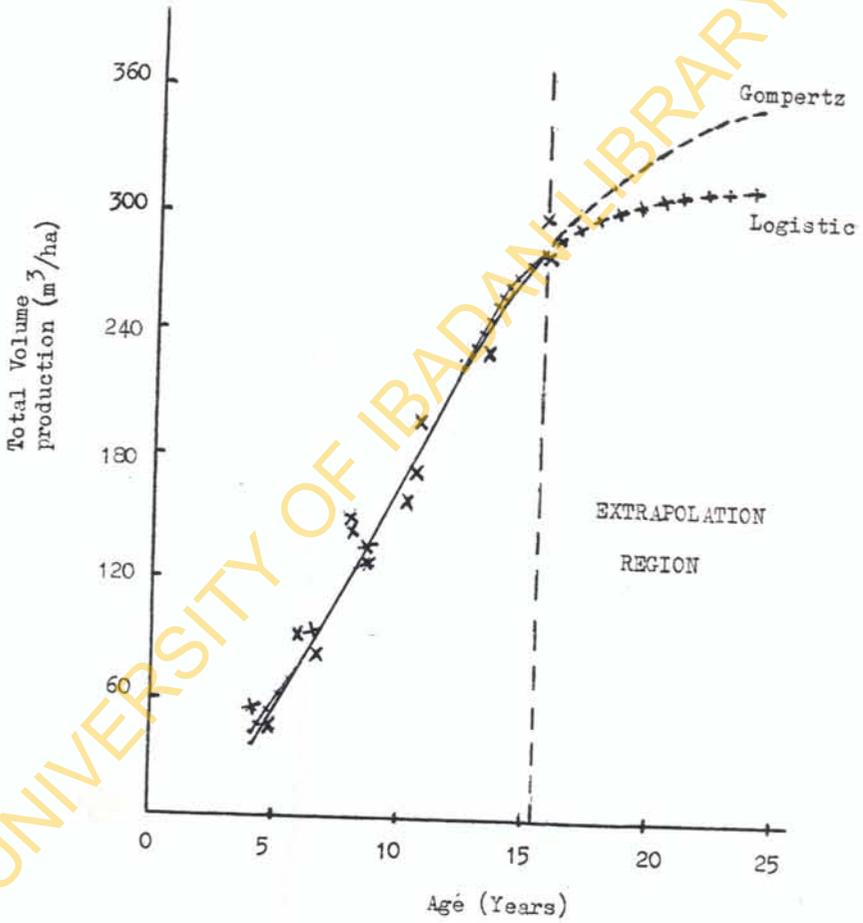


Fig. 5.4.2 (a)

Fitting of the average total volume production/ age curve for E. cloeziana

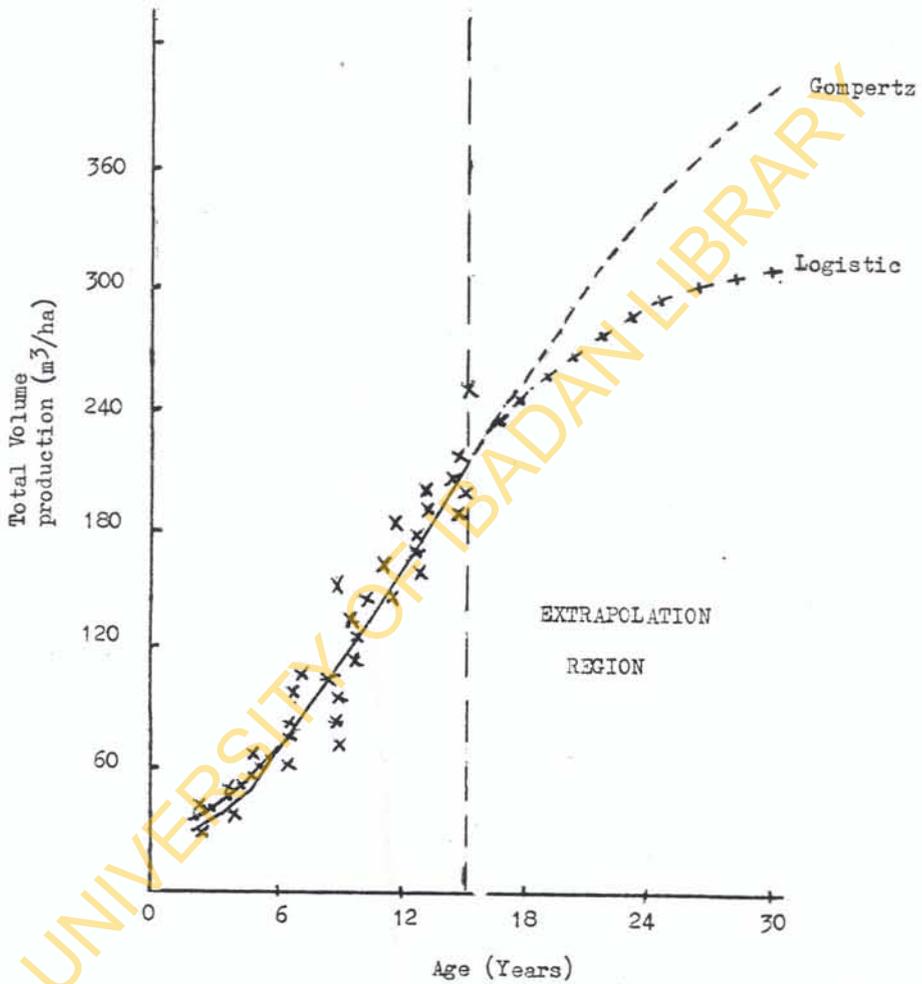


Fig. 5.4.2 (b)

Fitting of the average total volume production/ age curve for E. tereticornis

5.4.2.1 Fitting of total volume production/age curve for an assumed unthinned stand of P. caribaea.

For P. caribaea, the correlation coefficient of 0.716 obtained each from the Gompertz and the Logistic functions in fitting the average total volume production/age curve was somehow low. This was because unlike E. cloeziana and E. tereticornis, P. caribaea had a great variation in stocking (see Appendices 9(a - c)). An alternative method of obtaining a more realistic average total volume production/age curve was to fix the initial density and try further computations via the quadratic mean diameter (D_q) and the top height (H_d) . The quadratic mean diameter was the most highly correlated with the total volume production (TV) and the top height ($r = 0.865$ and 0.861 respectively). Therefore, if age and the number of trees/ha could be fixed or is known, it would be possible to predict D_q from H_d which itself could be predicted from age using the Gompertz parameters for P. caribaea in Table 6.3(a). After this, TV could be predicted from D_q . The two-stage prediction process was as follows:

Dq was predicted from H_d and N (number of trees per ha) from the following model

$$Dq = 14.7268 + 0.000318N \times H_d + 0.0146H_d^2 - 0.00621N \quad (39)$$

$$R = 0.88$$

$$DWST = 1.43$$

Next, TV was predicted from Dq , H_d and N from the following function

$$TV = -610.8530 + 6.8296Dq - 3.6262Dq^2 + 0.0891Dq^3 + 0.1664N - 0.0000388N^2 + 0.00431N \times H_d \quad (40)$$

$$R = 0.9844$$

$$DWST = 1.7307$$

For both models (39) and (40), all independent variables were significant at least up to 5% level.

For further calculations, the following assumptions were made :

(1) That at an initial spacing of 2.7m by 2.7m giving a total number of about 1370 trees per ha, at least 1200 trees would survive up to the age of 11 years in an unthinned stand at an average site.

(The average site is regarded as an area where the stand follows the growth rate of the average top height-age curve for P. caribaea using the estimated parameters , Table 6.3(a)).

(2) That as from the age of 12, when the canopy is becoming closed, mortality would reduce the number of standing trees at the rate of 30 trees per ha at 2-year intervals. This would finally leave a standing crop of about 750 trees per ha at the age of 40 years (see Table 5.4.2.1).

These assumptions were based on the average mortality rate in the records of unthinned permanent sample plots of P. caribaea in the study locations. However, the oldest unthinned plot for which such data existed was only 17 years. In Table 5.4.2.1, the top heights were estimated at 2-year intervals up to the age of 40 years using the Gompertz parameters in Table 6.3(a). The quadratic mean diameter, D_q , was estimated based on Model (39) while the total volume production, TV , was obtained at 2-year intervals using Model (40). Finally, the Gompertz and the Logistic functions were used to model the volume-age figures in Table 5.4.2.1 .

Table 5.4.2.1

Estimation of the quadratic mean diameter and total volume production from an assumed unthinned stand of P. caribaea at an average site.

Age (yrs)	Top height* (H_d in m)	H_d^2	Standing stems/ha (N)	N^2	NXH_d	D_q (cm)	D_q^2	D_q^3	Total volume (TV) m^3/ha
6	9.3	86.5	1200	1440000	11160	12.0	144.0	1728.0	32.3
8	11.4	130.0	1200	1440000	13680	13.4	179.6	2406.1	70.1
10	13.7	187.7	1200	1440000	16440	15.1	228.0	3443.0	114.9
12	16.0	256.0	1170	1368900	18720	17.0	289.0	4913.0	162.0
14	18.1	327.6	1140	1299600	20634	18.9	357.2	6751.3	214.2
16	20.1	404.0	1110	1232100	22311	20.7	428.5	8869.7	272.1
18	21.8	475.2	1080	1166400	23544	22.3	497.3	11089.6	332.5
20	23.4	547.6	1050	1102500	24570	23.9	571.2	13651.9	403.9
22	24.8	615.0	1020	1040400	25296	25.3	640.1	16194.3	476.7
24	26.0	676.0	990	980100	25740	26.5	702.3	18609.6	547.5
26	27.0	729.0	960	921600	25920	27.5	756.3	20796.9	612.8
28	27.9	778.4	930	864900	25947	28.5	812.3	23149.1	684.9
30	28.6	818.0	900	810000	25740	29.2	852.6	24897.1	738.5
32	29.2	852.6	870	756900	25404	29.8	888.0	26463.6	786.3
34	29.7	882.1	840	705600	24948	30.2	912.0	27543.6	817.8
36	30.1	906.0	810	656100	24381	30.6	936.4	28652.6	849.9
38	30.5	930.2	780	608400	23790	30.9	954.8	29503.6	873.8
40	30.8	948.6	750	562500	23100	31.2	973.4	30371.3	897.9

* Figures estimated from Gompertz parameters for P. caribaea in Table 6.3(a).

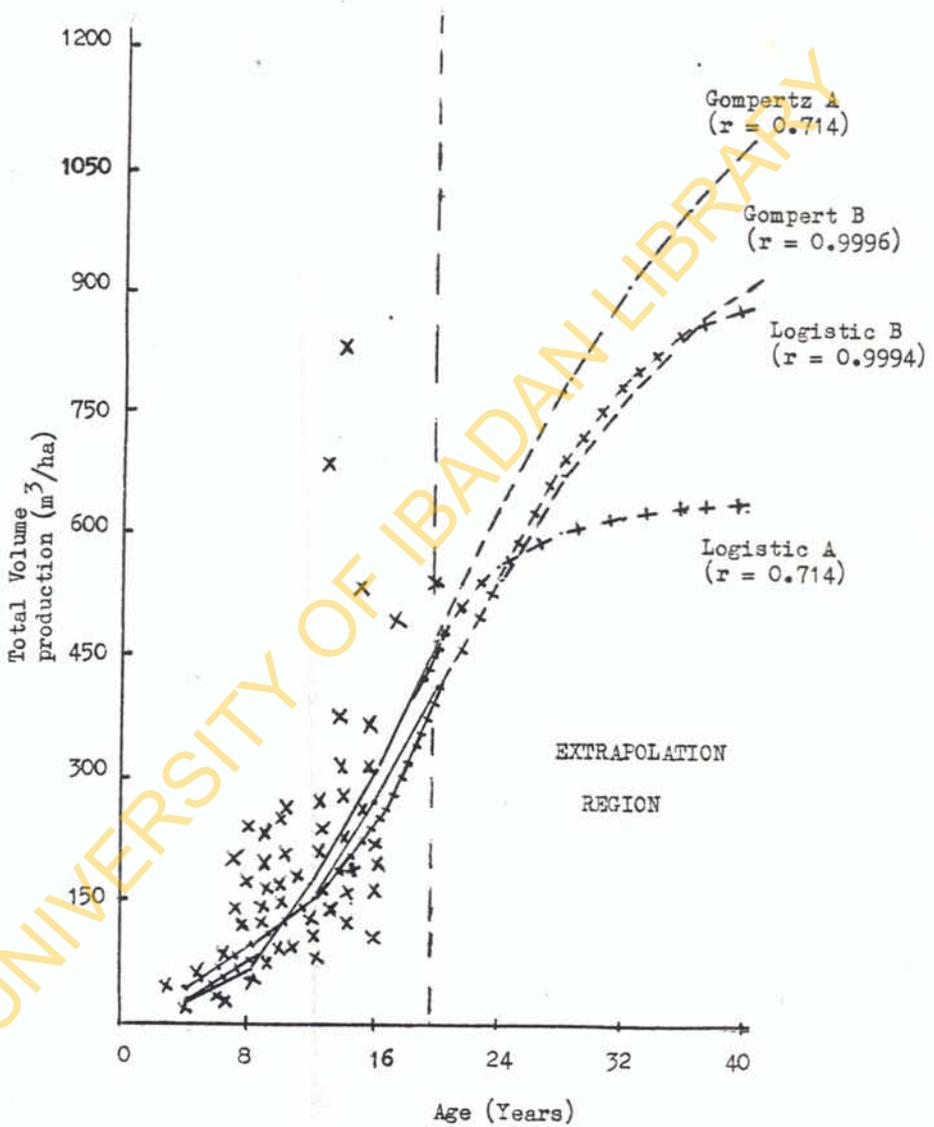


Fig. 5.4.2.1

Fitting of the average total volume production/ age curve for P. caribaea

CHAPTER 6

RESULTS AND DISCUSSION

In this chapter, attention will be focussed on the following:

- i) Results of preliminary analyses for the Weibull distribution.
- ii) Results of main analyses for the Weibull distribution
- iii) Models for the top height-age curves.
- iv) Volume prediction
- v) General discussion

6.1 Results of preliminary analyses for the Weibull distribution

It was noted that, in the trial runs involving E. tereticornis diameter data at Kabama, the values of 'b' and 'c' were higher when 'a' in the DAGOS subroutine was fixed at 0.0 as compared to when 'a' was assigned the value of $0.999 \times \text{MnD}$, i.e. 0.999 times the minimum diameter (see Table 6.1).

For the other subroutines, the WINGO, WWINGO, FITTER 1, FITTER 1.0, FITTER 2, FITTER 2.0 and HARTER, based on the maximum likelihood method (MLM), 'a' generally had slightly higher estimated values when the initial value of 'a' in DAGOS was $0.999 \times \text{MnD}$ as compared to when 'a' was given a starting value of 0.0. However, for the subroutines based on the MLM, it was observed that 'b' and 'c' had slightly lower estimated values or the same values when 'a' was assigned the initial value of $0.999 \times \text{MnD}$ (in DAGOS) as compared with the initial value of 0.0. Similar results were obtained at ages 6.3, 7.3, 9.25 and 12.5 years for the same plot (see Appendices 4(a - d)).

The results obtained from the next set of trial runs which involved the diameter data from a stand of P. caribaea at Afaka at ages 5.7, 9.7, 12.2 and 14 years were similar to what were obtained for E. tereticornis at Kabama.

It should be noted that, for the subroutines based on the MLM, the difference in the respective values of 'a', 'b' and 'c' was negligibly small for the same age or sample size when 'a' in DAGOS had initial values of 0.0 and $0.999 \times \text{MnD}$. This means

that the results from any of the subroutines based on the MLM will not vary significantly irrespective of whether 'a' is assigned a starting value of 0.0 or $0.999 \times \text{MnD}$ in the DAGOS subroutine.

6.1.1 Comparisons of the actual and predicted diameter distributions

The actual cumulative diameter frequency distribution curve and the cumulative diameter frequency distribution curve predicted by each subroutine were super-imposed for each set of measurements (Figs. 6.1.1(a - e) and 6.1.1(f - i)). In both E. tereticornis and P. caribaea stands, while the cumulative frequency distribution (c.f.d) curve from DAGOS showed the greatest deviation from the c.f.d curve of the actual data for all the ages of measurement, the c.f.d curves from the subroutines based on the MLM showed less deviation. Another point observed was that the c.f.d curve from each of the subroutines became closer to the c.f.d curve of the actual data with increasing age.

When the K-S two sample test was applied to

find out if there was a significant difference between the diameter distribution predicted by each subroutine and the distribution based on the actual data the following results were obtained.

(i) With respect to E. tereticornis, the summarised results of the test in Table 6.1.1(a) indicate that the c.f.d from all the subroutines showed a significant difference from the c.f.d of the actual data at the age of 4.3 years. This means that all the subroutines were not capable of efficiently describing the diameter data of the species at this age at Kabama.

(ii) The results from DAGOS still showed a significant difference up to the age of 7.3 years while the results from the subroutines based on the MLM did not show any significant difference as from the age of 6.3 years. This follows that the subroutines based on the MLM proved more efficient than DAGOS in describing the diameter data as from the age of 6.3 years.

(iii) With reference to the P. caribaea stand at Afaka, Table 6.1.1(b) indicates that the c.f.d from

DAGOS showed a significant difference from the c.f.d of the actual data at ages 5.7 and 9.7 years while the subroutines based on the MLM showed no significant difference for all ages of measurement (i.e. from 5.7 to 14 years) . However, the c.f.d from DAGOS did not show any significant difference from the c.f.d of the actual data at ages 12.2 and 14 years. This means that while all the subroutines based on the MLM could efficiently describe the diameter data for P. caribaea at Afaka from ages 5.7 to 14 years, the DAGOS subroutine was not capable of doing this until at least after 9.7 years.

All these findings have explained why it was necessary to select a subroutine based on the MLM for the determination of the Weibull parameters for the species.

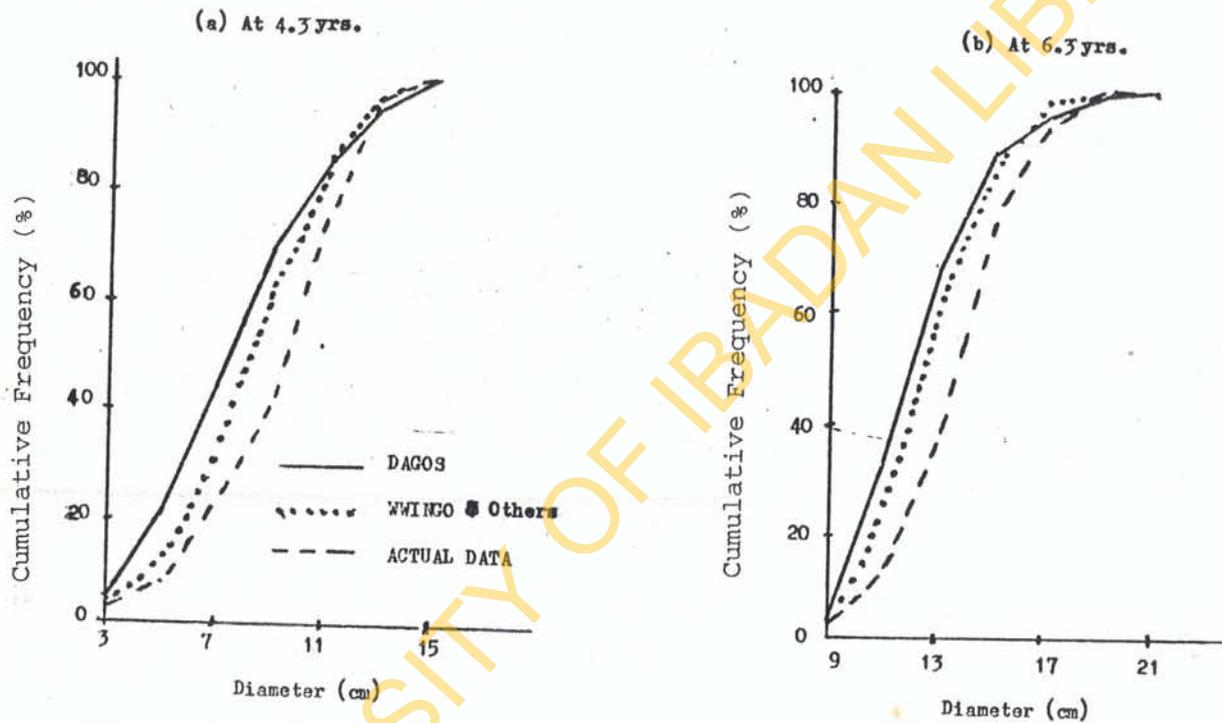


Fig. 6.1.1(a - b) Comparisons of the predicted c.f.d from DAGOS, WWINGO and others with the c.f.d of the actual data - E. tereticornis stand at Kabama.

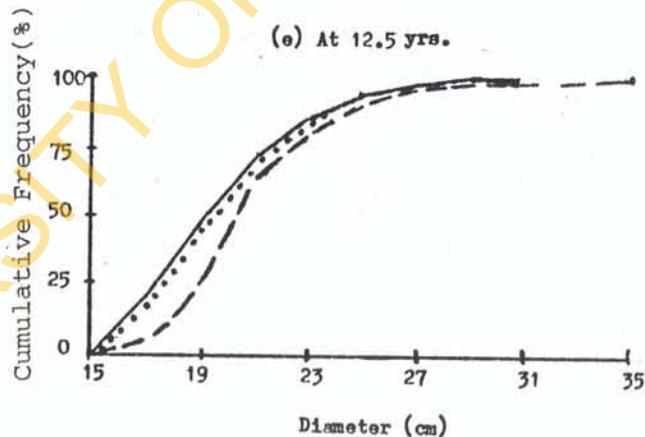
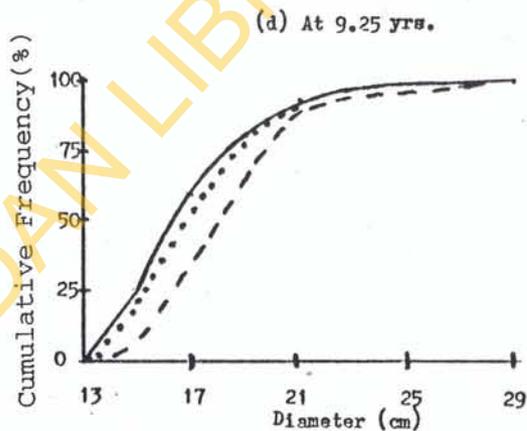
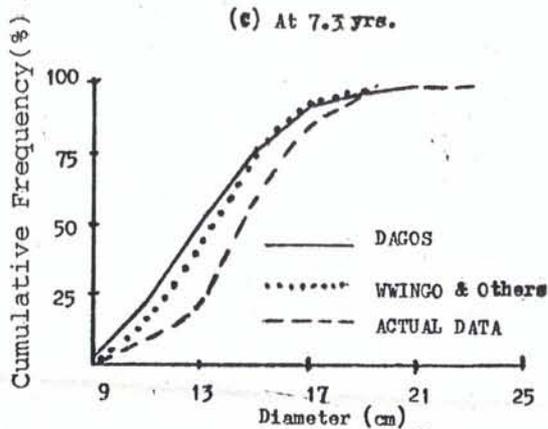


Fig. 6.1.1 (c - e)
 Comparisons of the c.f.d from DAGOS, WWINGO and others with the c.f.d of the actual data - E. tereticornis stand at Kabama.

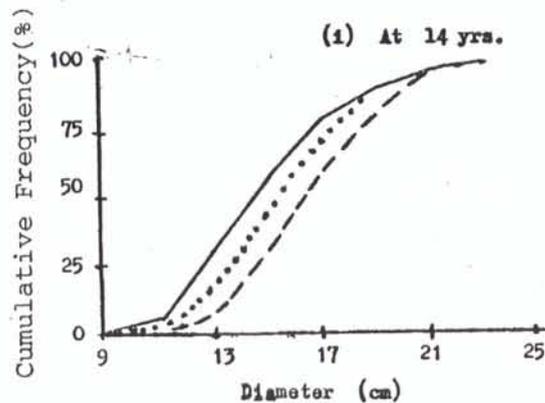
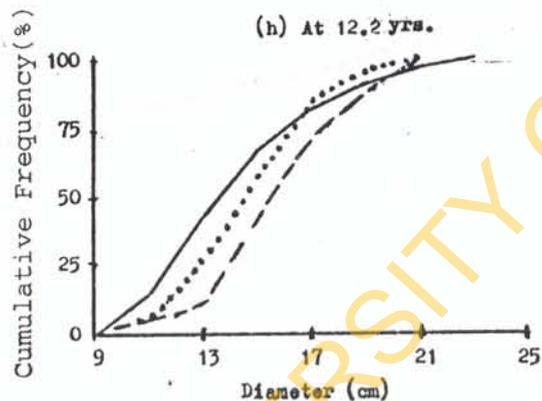
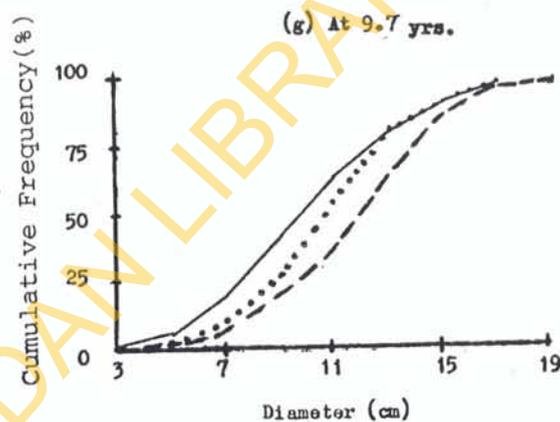
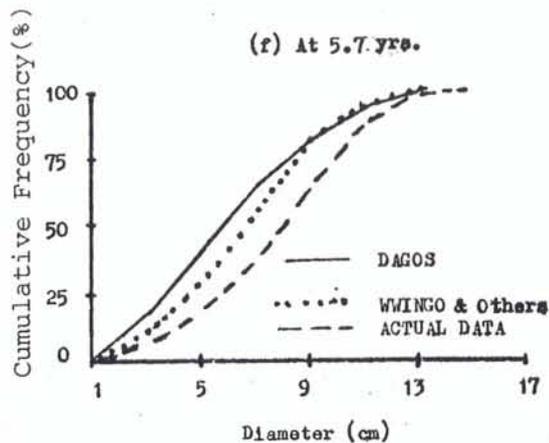


Fig. 6.1.1 (f - i) Comparisons of the predicted c.f.d from DAGOS, WINGO and others with the c.f.d from the actual data - *P. caribaea* stand at Afaka.

Table 6.1.1(a) Results of K-S¹⁾ test between the c.f.d of the actual data and the predicted c.f.d with different Weibull subroutines - Data from E. tereticornis at Kabama.

Age (Yrs)	DAGOS	Other subroutines based on Maximum Likelihood Method
4.30	*	*
6.30	*	N.s
7.30	*	N.s
9.25	N.s	N.s
12.50	N.s	N.s

* Significant at 5% level
N.s Not significant

Table 6.1.1(b) Results of K-S¹⁾ test between the c.f.d of the actual data and the predicted c.f.d with different Weibull subroutines - Data from P. caribaea at Afaka.

Age (Yrs)	DAGOS	Other subroutines based on Maximum Likelihood Method
5.7	*	N.s
9.7	*	N.s
12.2	N.s	N.s
14.0	N.s	N.s

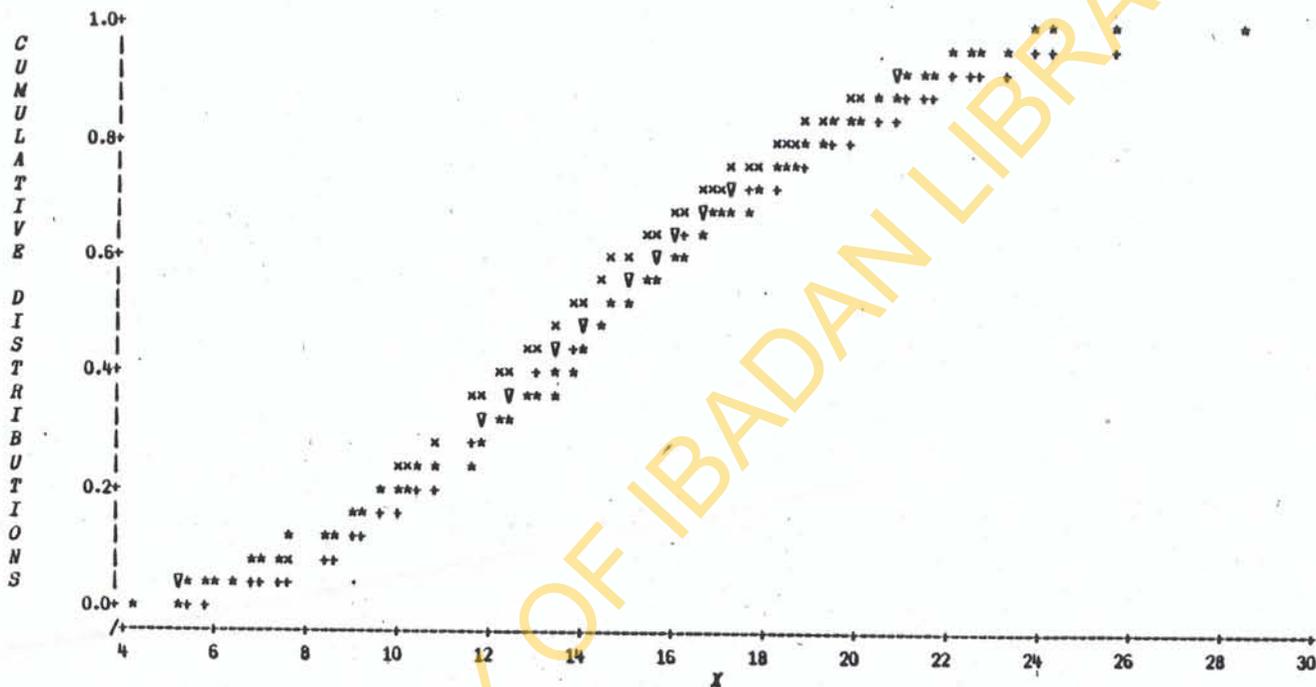
* Significant at 5% level
N.s Not significant

1) Kolmogorov-Smirnov two-sample test.

6.1.2 Comparisons of fittings from the WWINGO subroutine and gamma distribution

From the discussion in Section 6.1.1, it has been established that the subroutines based on the maximum likelihood method were more appropriate for the determination of the Weibull parameters for the species. Taking into consideration the advantages of shorter execution time and correction for sample size bias (for few observations), the WWINGO turned out to be the most eligible subroutine of the multi-Weibull programs for the data analyses.

A further area of study was to compare the results obtained from the WWINGO with those obtained using the gamma distribution since the latter was the next best model for describing the data. On comparing the results from the two fitting approaches, it was found that the WWINGO generally proved superior to the gamma distribution in terms of lower root mean square errors for most of the plot data tested. Fig. 6.1.2 shows the results obtained from the WWINGO and gamma distribution using the data from



* - EMPIRICAL CUMULATIVE DISTRIBUTION
 GAMMA SCALE PARAMETER = 0.5459314929 SHAPES PARAMETER = 8.030038492 LOCATION PARAMETER = 1.25
 169 OBSERVATIONS, FROM FILE *TEMP21 COMB1 SUBFILE CCLO CASE 1

WEIBULL	A	B	C	RMSE AGAINST DATA
+ GAMMA				2.63599E ⁻²
* D'AGOSTINO	3.99E00	1.1346E+1	2.10074E00	5.90229E ⁻²
▽ WWINGO	1.43E ⁻⁶	1.59762E+1	3.32936E00	2.49519E ⁻²

Fig. 6.1.2 Comparisons of the c.f.d from the WWINGO with the c.f.d from Gamma, DAGOSTINO and c.f.d from the actual data - E. cloeziana stand at Afaka (see Appendix 6).

the E. cloeziana stand at Afaka at the age of 8.2 years. Most of the other plot data from the other two species and at different ages gave this similar trend. This further supported the justification for selecting the WWINGO algorithm for the study.

6.2 Results of the main analyses for the Weibull distribution.

The encouraging results from the preliminary analyses made it possible to carry out the determination of the Weibull parameters for the species using the WWINGO subroutine. Hence further results on diameter distribution which will be discussed henceforth could be obtained.

6.2.1 Weibull distribution fitted to individual plot data and relationship between estimated parameters and age.

For each species, only the plot diameter data in which the Weibull distribution fitted well were considered for further prediction exercise. The

values of the determined Weibull parameters with good fittings at the various ages for the three species can be found in Appendices 7(a - c). If the determined parameters were highly correlated with age, then fairly simple Weibull parameter predictive models could have been obtained. However, when the values of each of the parameters were plotted against age for each of the species, there was no very high relationship observed.

Further analyses which also confirmed this showed that for E. cloeziana and P. caribaea, 'a' was the parameter most related to age with positive correlations, $r = 0.801$ and 0.652 respectively. The 'a' also had a positive correlation, $r = 0.580$, with age for E. tereticornis (Table 6.2.1). The 'b' still had positive correlation with age for E. cloeziana ($r = 0.574$), but with very low negative correlation with age for E. tereticornis ($r = - 0.231$) and almost with no correlation for P. caribaea ($r = 0.017$). The 'c' was most related to age in the E. tereticornis stands ($r = - 0.586$) while it had lower correlations with age for E. cloeziana and P. caribaea ($r = 0.336$ and $- 0.220$).

respectively). This follows that, in addition to age, the other stand attributes and site factors must be considered for the Weibull parameter predictive models.

Table 6.2.1 Correlations of the Weibull parameters with age for the under-mentioned species.

Weibull parameters	<u>E. cloeziana</u>	<u>E. tereticornis</u>	<u>P. caribaea</u>
a	0.801	0.580	0.652
b	0.574	- 0.231	0.017
c	0.336	- 0.586	- 0.220

6.2.2 Weibull distribution fitted to pooled diameter data of each species

When the Weibull parameters were determined for the pooled diameter data of each of the species and the predicted cumulative frequency distribution (c.f.d) and the c.f.d based on the actual data were compared using the K-S two-sample test, there was no good fit. This means that the Weibull was not capable of describing the diameter data from each

species in a pooled form. However, since the Weibull distribution had earlier fitted well to the individual plot data of each species at different ages of measurement, this further emphasised the importance of age as a variable for the Weibull parameter predictive models.

6.2.3 Correlations of the Weibull parameters with other stand attributes and site factors

Though age must be considered as an important variable in the prediction of the Weibull parameters, as already noted, these parameters were not highly correlated with age. The other stand attributes and the site factors must therefore be involved in the construction of the parameter models. Hence it will be necessary to examine which of the stand attributes (other than age) and site factors the Weibull parameters were highly correlated with.

For the three species, the 'a' parameter was more highly correlated with the minimum diameter (MnD) with $r = 0.845, 0.957$ and 0.969 for

P. caribaea, E. cloeziana and E. tereticornis respectively (Tables 6.2.3(a - c)). This was expected as the 'a' parameter marks the beginning of the point of distribution on the cumulative diameter frequency distribution curve.

The 'b' parameter varied in its correlation with different attributes for the different species. For example, E. cloeziana had the 'b' relatively highly correlated with SIF2 (i.e. H_d/age^2) with $r = - 0.799$. In the E. tereticornis stands, 'b' was still highly correlated with the minimum diameter. ($r = -0.864$). This of course confirms that, for E. tereticornis, the 'a' and 'b' parameters were highly correlated ($r = - 0.915$). In the case of P. caribaea, the 'b' parameter had the highest correlation with the soil depth, SD, ($r = 0.340$).

The 'c' parameter also varied in its correlation with different attributes for the different species. With regard to E. tereticornis, 'c' had the highest correlation of $- 0.794$ with either SIF1 (i.e. H_a/age) or the Dmx (the maximum diameter) and in the case of E. cloeziana, 'c' had the

highest correlation with N , the number of standing trees, ($r = -0.542$). In the *P. caribaea* stands, 'c' had the highest correlation with the maximum diameter ($r = -0.359$).

Considering both *E. tereticornis* and *P. caribaea*, generally it can be concluded that the stand parameters like the maximum diameter or top height/age which give an indication of site appear to be more correlated with the 'c' parameter.

The correlation coefficients of the 'b' and 'c' parameters with the stand attributes and site factors were generally low (Tables 6.2.3(a - c)). The construction of the parameter predictive models for the species had been made possible because, in most cases, the Weibull parameters were significantly correlated with each other. Considering *E. cloeziana*, for example, although the 'a' parameter was not significantly correlated with the 'b' and 'c' parameters, 'b' was significantly correlated with 'c' ($r = 0.588$). *E. tereticornis* had the 'a' parameter highly correlated with the 'b' and 'c' ($r = -0.915$ and -0.749 respectively) while

P. caribaea also had the 'a' parameter significantly correlated with 'b' and 'c' ($r = - 0.586$ and $- 0.755$ respectively). Tables 6.2.3(d - f) show the intercorrelations of the Weibull parameters, and correlations with the various transformed variables (derived from the parameters) for the three species.

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Table 6.2.3(a) Correlations of the Weibull parameters with stand attributes for E. cloeziana

	a	b	c	Age	MnD	MD	Dq	Dd	Dmx	BA	N	Hd	SIF1	SIF2
a	1.000													
b	-0.003	1.000												
c	0.038	0.588	1.000											
A	0.801	0.574	0.336	1.000										
MnD	0.957	0.244	0.241	0.914	1.000									
MD	0.776	0.627	0.422	0.984	0.902	1.000								
Dq	0.764	0.641	0.421	0.982	0.894	0.939	1.000							
Dd	0.673	0.723	0.378	0.955	0.820	0.977	0.982	1.000						
Dmx	0.648	0.740	0.388	0.945	0.789	0.967	0.972	0.985	1.000					
BA	0.645	0.741	0.396	0.954	0.801	0.967	0.971	0.985	0.972	1.000				
N	-0.737	-0.584	-0.542	-0.906	-0.865	-0.947	-0.946	-0.900	-0.908	-0.863	1.000			
Hd	0.705	0.681	0.329	0.975	0.838	0.975	0.978	0.979	0.975	0.986	-0.877	1.000		
SIF1	-0.725	-0.667	-0.484	-0.970	-0.870	-0.987	-0.987	-0.960	-0.959	-0.952	0.963	-0.953	1.000	
SIF2	-0.577	-0.799	-0.498	-0.912	-0.748	-0.953	-0.958	-0.967	-0.982	-0.962	0.922	-0.954	0.961	1.000

SIGNIFICANCE LEVELS (PROBABILITIES OF NO CORRELATION)

	a	b	c	Age	MnD	MD	Dq	Dd	Dmx	BA	N	Hd	SIF1	SIF2
a	0.000													
b	0.495	0.000												
c	0.440	0.005	0.000											
A	0.000	0.006	0.086	0.000										
MnD	0.000	0.163	0.167	0.000	0.000									
MD	0.000	0.002	0.040	0.000	0.000	0.000								
Dq	0.000	0.002	0.040	0.000	0.000	0.000	0.000							
Dd	0.001	0.000	0.060	0.000	0.000	0.000	0.000	0.000						
Dmx	0.001	0.000	0.055	0.000	0.000	0.000	0.000	0.000	0.000					
BA	0.001	0.000	0.051	0.000	0.000	0.000	0.000	0.000	0.000	0.000				
N	0.000	0.005	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			
Hd	0.000	0.000	0.090	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
SIF1	0.000	0.001	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
SIF2	0.006	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

CLOEZIANA
SELECT 'ALL'
18 CASES.

Table 6.2.3(b)

Correlations of the Weibull parameters with stand attributes and site factors for *E. tereticornis*

	a	b	c	Age	MnD	MD	Dq	Dd	Dmx	BA	N	Hd	SIF1	SIF2	RF	RD	SD
a	1.000																
b	0.915	1.000															
c	0.749	0.657	1.000														
A	0.580	0.231	0.586	1.000													
MnD	0.969	0.864	0.583	0.580	1.000												
MD	0.901	0.650	0.683	0.837	0.904	1.000											
Dq	0.886	0.624	0.694	0.858	0.884	0.998	1.000										
Dd	0.671	0.356	0.746	0.920	0.621	0.873	0.895	1.000									
Dmx	0.748	0.468	0.794	0.877	0.695	0.898	0.915	0.978	1.000								
BA	0.143	0.387	0.361	0.526	0.233	0.124	0.172	0.578	0.504	1.000							
N	0.833	0.804	0.281	0.315	0.909	0.723	0.690	0.321	0.388	0.556	1.000						
Hd	0.509	0.172	0.480	0.895	0.527	0.771	0.787	0.825	0.763	0.462	0.294	1.000					
SIF1	0.748	0.468	0.794	0.877	0.695	0.898	0.915	0.978	1.000	0.504	0.388	0.763	1.000				
SIF2	0.547	0.212	0.538	0.917	0.560	0.794	0.814	0.861	0.810	0.485	0.327	0.890	0.810	0.999			
RF	0.308	0.307	0.006	0.214	0.423	0.260	0.238	0.012	0.037	0.335	0.398	0.304	0.037	0.316	1.000		
RD	0.308	0.307	0.006	0.214	0.423	0.260	0.238	0.012	0.037	0.335	0.398	0.304	0.037	0.316	0.999	1.000	
SD	0.059	0.007	0.302	0.159	0.044	0.089	0.111	0.299	0.337	0.466	0.192	0.022	0.337	0.140	0.530	0.530	1.000

SIGNIFICANCE LEVELS (PROBABILITIES OF NO CORRELATION)

	a	b	c	Age	MnD	MD	Dq	Dd	Dmx	BA	N	Hd	SIF1	SIF2	RF	RD	SD
a	0.000																
b	0.000	0.000															
c	0.000	0.000	0.000														
A	0.001	0.144	0.001	0.000													
MnD	0.000	0.000	0.001	0.001	0.000												
MD	0.000	0.000	0.000	0.000	0.000	0.000											
Dq	0.000	0.000	0.000	0.000	0.000	0.000	0.000										
Dd	0.000	0.047	0.000	0.000	0.000	0.000	0.000	0.000									
Dmx	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000								
BA	0.256	0.033	0.045	0.004	0.141	0.285	0.215	0.001	0.007	0.000							
N	0.000	0.000	0.036	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
Hd	0.006	0.215	0.010	0.000	0.004	0.000	0.000	0.067	0.033	0.002	0.000						
SIF1	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.086	0.000					
SIF2	0.003	0.164	0.004	0.000	0.002	0.000	0.000	0.000	0.000	0.007	0.033	0.000	0.000				
RF	0.075	0.076	0.487	0.163	0.022	0.115	0.136	0.477	0.431	0.059	0.029	0.079	0.431	0.070	0.000		
RD	0.075	0.076	0.487	0.163	0.022	0.115	0.136	0.477	0.431	0.059	0.029	0.079	0.431	0.070	0.000	0.000	
SD	0.393	0.487	0.080	0.234	0.419	0.342	0.306	0.082	0.057	0.012	0.189	0.459	0.057	0.261	0.034	0.004	0.000

TERETRICORNIS, KABAMA, ETC.

SELECT 'ALL'

23 CASES.

Table 6.2.3(c) Correlations of the Weibull parameters with stand attributes and site factors for *P. caribaea*

	a	b	c	Age	MD	Dq	Dd	N	SIF1	SIF2	RF	SD	Hd	T	RD	BA	GSP	MnD	Dmx
a	1.000																		
b	0.586	1.000																	
c	0.755	0.810	1.000																
A	0.652	0.017	0.220	1.000															
MD	0.740	0.107	0.257	0.813	1.000														
Dq	0.744	0.094	0.293	0.799	0.996	1.000													
Dd	0.691	0.145	0.301	0.800	0.964	0.966	1.000												
N	0.509	0.028	0.267	0.315	0.610	0.620	0.548	1.000											
SIF1	0.253	0.051	0.017	0.498	0.281	0.272	0.200	0.062	1.000										
SIF2	0.477	0.002	0.143	0.875	0.588	0.577	0.566	0.219	0.759	1.000									
RF	0.105	0.117	0.231	0.077	0.022	0.028	0.103	0.266	0.435	0.101	1.000								
SD	0.013	0.340	0.166	0.043	0.249	0.229	0.303	0.090	0.318	0.167	0.035	1.000							
Hd	0.611	0.041	0.243	0.923	0.778	0.767	0.805	0.328	0.149	0.712	0.281	0.166	1.000						
T	0.376	0.242	0.087	0.448	0.665	0.668	0.681	0.277	0.112	0.161	0.101	0.640	0.527	1.000					
RD	0.131	0.207	0.286	0.054	0.016	0.004	0.045	0.253	0.337	0.071	0.951	0.250	0.213	0.085	1.000				
BA	0.170	0.316	0.305	0.323	0.031	0.004	0.114	0.618	0.157	0.332	0.266	0.299	0.319	0.137	0.362	1.000			
GSP	0.351	0.308	0.195	0.385	0.167	0.143	0.136	0.175	0.000	0.337	0.383	0.030	0.479	0.068	0.325	0.124	1.000		
MnD	0.845	0.172	0.348	0.781	0.895	0.880	0.797	0.649	0.364	0.606	0.026	0.063	0.706	0.468	0.028	0.110	0.328	1.000	
Dmx	0.702	0.091	0.359	0.749	0.932	0.936	0.982	0.555	0.134	0.507	0.180	0.340	0.778	0.669	0.116	0.075	0.146	0.763	1.000

SIGNIFICANCE LEVELS (PROBABILITIES OF NO CORRELATION)

	a	b	c	Age	MD	Dq	Dd	N	SIF1	SIF2	RF	SD	Hd	T	RD	BA	GSP	MnD	Dmx
a	0.000																		
b	0.000	0.000																	
c	0.000	0.000	0.000																
A	0.000	0.438	0.024	0.000															
MD	0.000	0.170	0.010	0.000	0.000														
Dq	0.000	0.201	0.004	0.000	0.000	0.000													
Dd	0.000	0.099	0.003	0.000	0.000	0.000	0.000												
N	0.000	0.400	0.008	0.002	0.000	0.000	0.000	0.000											
SIF1	0.011	0.326	0.437	0.000	0.005	0.007	0.037	0.291	0.000										
SIF2	0.000	0.489	0.102	0.000	0.000	0.000	0.000	0.025	0.000	0.000									
RF	0.174	0.150	0.019	0.247	0.420	0.399	0.179	0.008	0.000	0.184	0.000								
SD	0.452	0.001	0.070	0.351	0.012	0.020	0.003	0.213	0.001	0.069	0.378	0.000							
Hd	0.000	0.356	0.014	0.000	0.000	0.000	0.000	0.001	0.093	0.090	0.005	0.070	0.000						
T	0.000	0.015	0.220	0.000	0.000	0.000	0.000	0.006	0.159	0.076	0.184	0.000	0.000	0.000					
RD	0.122	0.032	0.004	0.314	0.442	0.484	0.343	0.011	0.001	0.264	0.000	0.012	0.028	0.225	0.000				
BA	0.065	0.002	0.002	0.001	0.392	0.485	0.155	0.000	0.082	0.001	0.008	0.003	0.001	0.111	0.000	0.000			
GSP	0.000	0.002	0.041	0.000	0.069	0.101	0.114	0.059	0.499	0.001	0.000	0.394	0.000	0.273	0.001	0.135	0.000		
MnD	0.000	0.063	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.407	0.287	0.000	0.000	0.400	0.164	0.001	0.000	
Dmx	0.000	0.209	0.000	0.000	0.000	0.000	0.000	0.000	0.117	0.000	0.054	0.001	0.000	0.000	0.151	0.254	0.097	0.000	0.000

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Table 6.2.3(d) Intercorrelations of the Weibull parameters for E. cloeziana.

		a	a ²	1/a	1/a ²	1/a ³	b	b ²	1/b	1/b ²	o	o ²	1/o	1/o ²
a	1) r =	-	-	-	-	-	-0.003	0.038	-0.062	-0.088	0.038	0.014	-0.081	-0.099
	2) p.n.o =	-	-	-	-	-	0.495	0.439	0.402	0.363	0.440	0.478	0.374	0.347
b	r =	-0.003	0.021	0.184	0.151	0.137	-	-	-	-	0.580	0.578	-0.601	-0.605
	p.n.o =	0.495	0.465	0.232	0.274	0.292	-	-	-	-	0.005	0.005	0.004	0.003
c	r =	0.038	0.068	-0.335	-0.438	-0.465	0.580	0.565	-0.626	-0.639	-	-	-	-
	p.n.o =	0.440	0.393	0.086	0.034	0.025	0.005	0.007	0.002	0.002	-	-	-	-

Table 6.2.3(e) Intercorrelations of the Weibull parameters for E. tereticornis.

		a	a ²	1/a	1/a ²	b	b ²	1/b	1/b ²	o	o ²	1/o	1/o ²
a	1) r =	-	-	-	-	-0.915	-0.839	0.901	0.663	-0.749	-0.617	0.826	0.799
	2) p.n.o =	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
b	r =	-0.915	-0.853	0.540	0.393	-	-	-	-	0.657	0.539	-0.718	-0.685
	p.n.o =	0.00	0.00	0.020	0.031	-	-	-	-	0.00	0.003	0.00	0.00
c	r =	-0.749	-0.724	0.225	0.109	0.657	0.616	-0.687	-0.673	-	-	-	-
	p.n.o =	0.00	0.00	0.149	0.310	0.00	0.00	0.00	0.00	-	-	-	-

- 1) Refers to correlation coefficient.
- 2) Means probability of no correlation.

Table 6.2.3 (f) Intercorrelations of the Weibull parameters for P. caribaea

		a	a ²	a ³	1/a	1/a ²	1/a ³	b	b ²	b ³	1/b	1/b ²	1/b ³	o	o ²	o ³	1/o	1/o ²	1/o ³
a	1) r =	-	-	-	-	-	-	0.586	0.578	0.550	0.521	0.461	0.400	0.755	0.693	0.611	0.742	0.705	0.674
	2) p.n.o =	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
b	r =	0.506	0.329	0.167	0.284	0.233	0.209	-	-	-	-	-	-	0.810	0.778	0.707	0.703	0.633	0.581
	p.n.o =	0.00	0.001	0.066	0.05	0.018	0.030	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00
o	r =	0.755	0.540	0.373	0.172	0.139	0.131	0.810	0.782	0.730	0.749	0.674	0.593	-	-	-	-	-	-
	p.n.o =	0.00	0.00	0.00	0.062	0.109	0.123	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-

- 1) Refers to correlation coefficient.
- 2) Means probability of no correlation.

6.2.4 Weibull parameter predictive models

The Weibull parameter predictive models obtained varied from one species to another. Generally, the predictive models appeared to be relatively simple for E. cloeziana, but more complex for E. tereticornis and P. caribaea.

The best models for predicting 'a', 'b' and 'c' parameters from the stand attributes and site factors are as follows:

E. cloeziana

$$a' = 2.4866 - 0.9898MnD + 0.09887MnD^2 \quad (41)$$

Coefficient of multiple correlation (R) = 0.9860

Durbin-Watson Statistic (DWST) = 3.3700

Root mean square error (RMSE) = 0.5969

$$b' = -27.7964 + 4.5260MD - 0.1640MD^2 + 2.1607A \quad (42)$$

R = 0.9700

DWST = 1.7139

RMSE = 0.7527

$$c' = e^{(0.5524 - 0.0427Dq - 0.1753SMD^2 - 73.3840b^2 + 3.7179MR)} \quad (43)$$

$$R = 0.9167$$

$$DWST = 2.1299$$

$$RMSE = 0.2387$$

where:

$$SMD^2 = \left\{ \frac{MnD + Dd}{MD} \right\}^2$$

$$MR = MD/Dmx$$

e = exponential
constant.

All independent variables were significant at least up to 5% level.

E. tereticornis

$$a' = -2.3187 + 1.2126MnF \quad (44)$$

$$R = 0.9700$$

$$DWST = 1.1420$$

$$RMSE = 1.5616$$

$$b' = e^{(3.1775 + 0.05060A - 0.00324MnD^2 - 0.15865SMD^3)} \quad (45)$$

$$R = 0.9501$$

$$DWST = 1.6620$$

$$RMSE = 1.3106$$

$$c' = e^{(6.8935 - 1.7248b^{-2} + 655.5028b^{-3} - 0.002104N + 0.06786A - 0.2197MD)} \quad (46)$$

$$R = 0.9714$$

$$DWST = 2.2346$$

$$RMSE = 0.5542$$

where :

$$MnF = \left\{ \frac{MnD}{MD} \right\}^2 \times Dd$$

$$SMD^3 = \left\{ \frac{MnD + Dd}{MD} \right\}^3$$

All independent variables were significant at least up to 5% level.

P. caribaea

$$a' = 2.9390 + 2315.9908NR + 1.4920MnD \\ + 0.01663Dq^2 - 2.31006MD + 0.8399Dmx \quad (47)$$

$$R = 0.9120$$

$$DWST = 1.4100$$

$$RMSE = 2.4011$$

$$1) \quad b' = -3957.0479 - 1.01507a' + 1.1336MD \\ + 0.036434RD + 6109.4510SMD \\ - 3150.7991SMD^2 + 541.3633SMD^3 \\ + 0.1715c'^2 \quad (48)$$

$$R = 0.8701$$

$$DWST = 1.6382$$

$$RMSE = 2.1632$$

-
- 1) In this type of situation, 'a' and 'c' must be evaluated first before 'b' can be evaluated.

$$c' = e^{(1.3198 - 0.00007031N \times Dq - 0.1864a' + 250.8590Dq^{-1} + 226.8812MD^{-1} + 0.05098BA - 1.7792DFM^2 + 1.3077DFM^3 + 0.0023975a' \times Dmx)} \quad (49)$$

$$\begin{aligned} R &= 0.8540 \\ DWST &= 1.5551 \\ RMSE &= 0.9698 \end{aligned}$$

where:

N = Number of standing trees/ha
 NR = GSF/N
 GSF = Average relative growing space per tree as the stand ages (see Section 4.2.3).

RD = Length of rainy days per year.

$$SMD = \left\{ \frac{MnD + Dd}{MD} \right\}$$

$$DFM = \left\{ \frac{Dmx - MnD}{MD} \right\}$$

All other symbols are interpreted in Section 4.2.3

6.2.4.1 Weibull parameter predictive models for the individual species.

As the parameter predictive models vary from one species to another, attention will now be given to the discussion of the predictive models for each species.

(i) Weibull parameter predictive models for E. cloeziana.

The predictive models for the 'a' and 'b' parameters were obtained directly from the stand attributes. Although the 'b' parameter was significantly correlated with SIF2 (H_d/age^2 , $r = 0.779$) as earlier discussed, the introduction of the arithmetic mean diameter (MD) and MD^2 and age as independent variables rendered SIF2 insignificant in the model for 'b'. This is due to a condition of multi-collinearity where the displaced independent variable is highly correlated with the variables that displace it (Johnston, 1963). Of course the mean diameter and age may be more accurately

determined than the top height (H_d) .

The 'c' parameter model was obtained indirectly from the predicted 'b' parameter and some combinations of the stand attributes.

Having constructed the Weibull parameter models, it is worthwhile to test them first of all with the original data in order to see how well the original Weibull parameters compare with the newly predicted parameters based on the constructed models. In line with this objective, the models were tested on the original 18 sets of data used for constructing the models. The predicted 'a' , 'b' and 'c' parameters were then compared with the original Weibull parameters (Table 6.2.4.1(a)). It was found that the predicted parameters did not deviate much from the previously observed Weibull parameters. It was also noted that generally out of the three parameters, the predicted 'c' showed the smallest deviation from the previously observed values with the lowest root mean square error (RMSE) of 0.2387 followed

by the 'a' parameter with the RMSE of 0.5969 and finally the 'b' parameter with the RMSE of 0.7527.

Table 6.2.4.1 (a) Observed and predicted Weibull parameters for E. cloeziana

No*	Age	N	OBSERVED			PREDICTED		
			a	b	c	a	b	c
1	4.2	1006	3.59E ⁻⁷	12.43	3.54	1.09E ⁻¹	11.40	3.59
2	5.6	782	8.90E ⁻⁷	16.00	4.48	1.37E ⁻²	15.42	4.39
3	8.2	765	2.70E ⁻⁷	19.34	4.46	5.72E ⁻²	18.78	4.67
4	10.5	723	7.10E ⁻⁷	21.43	4.60	4.03E ⁻¹	20.60	4.87
5	12.5	557	8.27E ⁻⁷	16.22	4.27	6.98E ⁻²	16.55	4.48
6	15.5	515	8.77E ⁻⁷	17.64	4.37	9.89E ⁻²	17.07	4.16
7	4.2	1098	1.32E ⁻⁶	10.77	3.05	4.57E ⁻²	11.13	2.95
8	5.6	798	1.94E ⁻⁶	15.20	4.87	2.02E ⁻¹	15.50	4.47
9	8.2	798	7.90E ⁻⁷	19.31	4.46	2.61E ⁻¹	18.78	4.40
10	10.5	790	2.28E ⁻⁶	21.18	4.39	2.61E ⁻¹	21.15	4.45
11	12.5	590	8.89E ⁻⁷	15.46	3.93	8.01E ⁻²	16.85	4.18
12	15.5	582	7.42E ⁻⁷	18.64	4.33	8.01E ⁻²	18.49	4.19
13	4.7	922	1.79E ⁻⁶	13.16	4.32	9.06E ⁻²	13.06	4.29
14	5.5	883	2.30E ⁻⁷	16.46	4.09	4.57E ⁻²	17.28	4.16
15	8.5	712	3.20E ⁻⁷	19.77	4.94	2.49E ⁻²	18.76	4.30
16	4.7	927	8.80E ⁻⁷	12.63	3.56	1.09E ⁻¹	12.64	3.83
17	6.5	900	1.43E ⁻⁷	15.98	3.33	1.09E ⁻¹	17.43	3.41
18	8.5	756	1.35E ⁻⁷	19.18	3.51	5.72E ⁻²	19.90	3.61

* Refers to serial number of data set

(ii) Weibull parameter models for E. tereticornis

Unlike E. cloeziana, the model for the 'a' parameter for E. tereticornis was obtained from a combination of the stand attributes while the model for 'b' was

obtained from the stand attributes and some combinations of them. However, the 'c' model was obtained in a way similar to that of E. cloeziana, i.e., from the predicted 'b' and some of the stand attributes.

On testing the models on the 23 sets of the original data, it was also found that the predicted Weibull parameters did not deviate very much from the originally observed parameters (Table 6.2.4.1(b)). Generally, however, the deviation seemed to be greater than that of E. cloeziana especially when the corresponding root mean square errors for each of the parameters were compared (Table 6.2.4.1(c)).

Table 6.2.4.1 (b) Observed and predicted Weibull parameters for E. tereticornis

No*	Age	N	OBSERVED.			PREDICTED.		
			a	b	c	a	b	c
1	6.3	712	8.93F00	6.18	2.96	8.51F00	7.34	3.05
2	7.3	712	9.24F00	6.82	2.85	8.59F00	7.70	2.87
3	9.25	416	1.47F+1	4.89	1.92	1.43F+1	5.67	2.02
4	12.5	416	1.76F+1	4.80	1.54	1.79F+1	4.83	1.69
5	14.5	416	1.83F+1	5.54	1.58	1.89F+1	4.78	1.40
6	6.3	1166	1.82F ⁻⁶	13.26	4.67	1.32F ⁻¹	14.48	4.96
7	7.3	1166	1.17F ⁻⁶	14.07	4.68	8.71F ⁻³	13.21	4.05
8	9.25	1166	8.40F ⁻⁷	15.40	4.62	1.31F00	14.22	3.92
9	12.5	1157	2.90F ⁻⁷	17.08	4.41	8.92F ⁻¹	17.22	4.16
10	14.5	1148	2.01F00	15.62	3.79	1.61F00	17.08	4.33
11	6.3	527	1.54F00	13.41	8.26	6.76F00	9.11	6.70
12	7.3	527	4.37F00	11.58	6.37	7.40F00	9.19	5.71
13	9.25	296	1.27F+1	6.05	3.35	1.20F+1	7.21	3.78
14	12.5	296	1.38F+1	7.34	3.40	1.31F+1	7.65	3.24
15	14.5	296	1.34F+1	8.72	3.59	1.24F+1	8.97	3.81
16	4.7	1063	1.81F00	11.33	4.53	7.22F ⁻¹	12.57	4.64
17	7.1	1053	1.41F00	14.26	4.18	3.76F ⁻¹	14.18	3.93
18	10.5	1044	3.74F00	13.91	3.18	1.52F00	14.47	3.47
19	12.6	795	1.12F+1	8.52	1.86	9.95F00	8.29	1.84
20	14.5	795	1.12F+1	9.75	1.91	9.53F00	9.20	1.93
21	4.0	975	1.51F ⁻⁶	12.17	5.05	1.51F ⁻¹	12.35	6.49
22	6.2	975	1.65F ⁻⁶	14.79	5.16	2.03F ⁻¹	14.00	5.12
23	8.2	975	1.83F ⁻⁶	16.00	5.24	2.15F ⁻¹	16.32	5.32

* Refers to serial number of data set.

Table 6.2.4.1(c) Comparisons of root mean square errors of the predicted Weibull parameters for the three species.

Weibull parameters	<u>E. cloeziana</u>	<u>E. tereticornis</u>	<u>P. caribaea</u>
a	0.5969	1.5616	2.4011
b	0.7527	1.3106	2.1632
c	0.2387	0.5542	0.9698

(iii) Weibull parameter models for P. caribaea

In this case, the 'a' parameter was predicted first and directly from the stand attributes, but with more explanatory variables than those involved in the 'a' model for E. cloeziana or E. tereticornis. Moreover, 'c' had to be predicted next to 'a' since 'b' was predicted from the predicted 'a' and 'c' parameters. The 'c' parameter itself was predicted from the predicted 'a', some of the stand attributes and some combinations of them. The 'b' model included, in addition to the predicted 'a' and 'c' parameters, some stand attributes, some combinations of stand attributes and one environmental factor, the number of rainy days per year. Although it has been mentioned that 'b' was significantly correlated with soil depth, the introduction of the independent variable, $(MnD + Dd)/MD$, rendered it insignificant in the 'b' model.

When the constructed models were tested on the original 80 sets of data from the various study locations, it was found that the predicted Weibull parameters did not deviate very much from the previously observed parameters (Table 6.2.4.1(d)). The deviation however seemed to be greater than what was observed in the E. cloeziana or E. tereticornis stands. Comparisons of the root mean square errors for the predicted Weibull parameters from the three species in Table 6.2.4.1(c) of course confirmed this. It was also observed from the same table that for both E. tereticornis and P. caribaea the 'b' parameter had lower root mean square errors than the 'a' parameter unlike the situation for E. cloeziana where the 'a' had a lower root mean square error than the 'b' parameter .

Table 6.2.4.1(d) Observed and predicted Weibull parameters for P. caribaea

No*	Age	N	O B S E R V E D .			P R E D I C T E D .		
			a	b	c	a	b	c
1	9.7	3280	1.34E-1	12.42	5.25	2.24E-1	11.83	4.90
2	12.2	3280	2.50E00	11.66	4.23	1.87E-1	13.30	4.47
3	14.0	3246	2.26E00	12.56	4.12	6.29E-2	14.68	4.67
4	9.7	1639	6.50E00	7.52	3.15	5.00E00	8.82	3.93
5	12.2	1327	1.00E+1	7.28	2.90	7.67E00	8.71	3.11
6	14.0	1327	1.00E+1	8.11	3.06	7.81E00	9.36	3.05
7	9.7	1275	5.92E00	7.99	2.89	9.53E00	9.91	2.12
8	12.2	1275	4.38E00	13.40	4.07	9.52E00	8.02	2.04
9	14.0	1275	4.01E00	14.71	4.23	9.30E00	8.71	2.41
10	9.7	520	8.90E00	7.01	1.00	7.71E00	6.62	0.89
11	12.2	520	1.05E+1	8.79	1.00	7.87E00	9.57	1.00
12	14.0	520	1.05E+1	9.71	1.00	8.26E00	10.13	0.91
13	9.7	3417	4.96E00	6.93	2.63	3.79E00	6.46	2.52
14	12.2	2084	7.99E00	6.77	2.44	7.19E00	5.91	2.55
15	14.0	2084	7.65E00	7.00	2.76	6.07E00	8.28	3.02
16	9.7	1835	2.48E00	12.38	4.32	3.38E00	10.68	3.63
17	12.2	1210	5.07E00	13.90	5.52	7.23E00	11.27	3.45
18	14.0	1210	5.68E00	13.99	5.20	8.03E00	10.98	3.23
19	9.7	1275	2.24E00	14.15	5.23	4.91E00	11.58	4.17
20	12.2	1230	2.20E-6	19.50	5.96	3.42E00	17.35	5.02
21	14.0	1230	1.90E-6	20.20	5.83	3.31E00	17.83	4.88
22	9.7	956	1.09E+1	4.88	1.42	8.26E00	7.28	2.58
23	12.2	956	1.31E+1	5.79	1.45	9.74E00	8.24	2.41
24	14.0	956	1.40E+1	5.81	1.00	1.04E+1	7.96	1.76
25	9.7	3417	5.02E00	7.77	2.88	3.34E00	7.65	2.75
26	12.2	1948	7.21E00	9.37	3.15	5.95E00	9.24	2.94
27	14.0	1948	7.77E00	9.63	3.99	6.47E00	9.95	3.24
28	9.7	1991	1.00E-7	15.06	5.95	9.00E-1	15.27	6.00
29	12.2	1991	5.90E-7	17.70	5.75	9.32E-1	18.73	5.98
30	14.0	1991	1.90E-1	18.17	5.65	1.17E00	19.62	6.10
31	9.7	1457	2.74E00	12.72	4.76	2.79E00	14.33	5.21
32	12.2	1412	7.67E00	10.69	3.33	4.97E00	13.49	3.91
33	14.0	1412	7.50E00	11.87	3.48	5.22E00	14.38	4.01
34	9.7	936	3.50E-6	15.80	7.47	3.84E00	13.62	5.47
35	12.2	936	2.72E00	16.25	6.37	6.83E00	11.64	3.52
36	14.0	936	8.75E00	10.87	3.79	7.80E00	11.37	3.41
37	9.7	3896	2.93E00	8.94	3.39	2.36E00	7.79	3.04
38	12.2	3896	3.35E00	10.16	3.16	3.11E00	8.70	3.15
39	14.0	3861	4.46E00	9.55	2.83	3.73E00	8.96	2.84
40	9.7	2030	4.88E00	9.17	3.37	4.38E00	8.51	3.33

* Refers to serial number of data set

Table 6.2.4.1 (d) CONTD.

No	Age	N	OBSERVED .			PREDICTED .		
			a	b	c	a	b	c
41	12.2	1952	6.27F00	10.01	2.95	5.56F0	9.08	2.85
42	14.0	1952	6.41F00	10.52	2.93	5.70F0	9.79	2.95
43	9.7	1366	2.62F00	13.21	4.89	2.55F0	14.18	4.80
44	12.2	1366	4.14F00	14.54	4.42	3.20F0	16.67	4.85
45	14.0	1366	4.35F00	15.22	4.44	3.69F0	16.52	4.48
46	9.7	728	9.50F00	5.59	1.01	7.61F0	5.84	1.30
47	12.2	728	1.24F+1	5.98	1.08	1.04F1	6.55	1.55
48	14.0	728	1.34F+1	6.01	1.01	1.06F1	7.73	1.46
49	9.1	1661	1.07F+1	3.52	1.27	7.29F0	5.89	2.76
50	12.7	1661	1.21F+1	4.37	1.00	7.37F0	8.36	2.45
51	14.6	1411	4.53F00	15.10	5.47	7.38F0	12.06	3.65
52	16.1	1245	1.64F+1	5.00	1.32	1.24F1	8.30	2.60
53	9.5	1661	2.00F 8	17.73	5.06	2.06F0	16.67	5.24
54	10.5	1044	6.04F00	14.37	4.44	6.25F0	13.40	3.59
55	18.2	1044	6.86F00	19.84	4.27	8.02F0	20.03	4.96
56	20.1	817	1.63F+1	12.53	2.94	1.60F1	12.65	2.86
57	8.4	989	3.67F00	11.87	2.82	4.68F0	12.39	4.46
58	10.3	961	3.09F00	15.56	3.36	4.12F0	16.30	4.65
59	12.7	896	6.02F00	14.48	3.04	6.72F0	14.25	3.23
60	8.8	933	8.84F00	9.44	2.47	8.33F0	9.80	2.42
61	10.7	748	1.36F+1	7.62	1.89	1.43F1	6.55	1.55
62	13.7	307	1.43F+1	10.52	1.00	1.25F1	10.91	0.91
63	16.7	283	2.10F+1	11.13	1.01	2.17F1	9.14	0.87
64	21.9	283	2.38F+1	13.34	1.02	2.36F1	13.54	1.17
65	27.0	260	3.12F+1	8.89	1.02	3.23F1	9.31	0.97
66	10.9	1412	8.60F00	3.93	1.01	5.22F0	7.34	2.25
67	13.8	1412	2.50F 6	15.50	6.61	3.88F0	13.97	4.68
68	15.7	914	1.02F+1	7.77	4.64	1.07F1	7.60	2.59
69	10.9	1412	9.20F00	4.75	1.00	7.90F0	9.72	1.42
70	13.8	1412	8.58F00	8.37	1.69	7.51F0	10.29	1.94
71	15.7	831	1.59F+1	4.70	1.06	1.45F1	6.71	1.47
72	10.9	1495	2.09F00	14.25	3.25	5.77F0	8.41	1.20
73	13.8	1495	4.00F 8	18.14	3.74	2.20F0	17.03	4.13
74	15.7	831	1.71F+1	4.36	1.20	1.83F1	4.81	1.09
75	10.9	1412	1.88F 1	13.72	4.54	8.95F0	8.40	1.82
76	13.8	1412	1.04F+1	4.44	1.06	1.04F1	6.74	1.27
77	15.7	831	1.43F+1	4.40	1.10	1.55F1	3.09	1.11
78	10.9	1578	7.38F00	5.59	1.42	7.50F0	6.97	1.81
79	13.8	1412	8.60F00	5.76	1.00	8.69F0	5.44	0.87
80	15.7	914	1.30F+1	4.50	1.01	1.38F1	3.63	1.14

6.2.4.2 Testing of the Weibull parameter predictive models in new stands.

For the three species, the constructed models have been tested in the experimental stands. In the majority of cases, the predicted and the observed values were found to be consistent. The next exercise was to test the efficiency of the models in new stands. The unfortunate aspect of this exercise was that although data were available from new stands, there were no older stands outside the range of experimental data.

There are at least two methods of testing the Weibull parameter models in new stands. One method is to collect diameter data from the new stands and then use the WWINGO subroutine of the multi-Weibull programs to determine the 'a', 'b' and 'c' parameters. Then using the same data from the new stands, the constructed models can be used to predict the Weibull parameters. These predicted parameters can then be compared with the previously determined parameters (Rustagi, 1978). For the

avoidance of doubt, the t-test or the Chi-square can be used to find out significant differences, if any, between the predicted and the previously observed Weibull parameters.

The second method of testing is to predict the Weibull parameters from the new stand data based on the constructed models. On achieving this, the predicted Weibull parameters are used to generate cumulative frequency distribution (e.g at 2 cm diameter class interval) using Model (26). By the application of the K-S two-sample test, the actual cumulative frequency distribution is then tested against the cumulative frequency distribution obtained from the predicted Weibull parameters. This second method was the one used in testing the models as it did not involve the re-running of the expensive multi-Weibull programs.

(i) New stands of E. cloeziana

Out of the five plots on which the models were tested, only three of these had been measured

recently. The remaining two were from past records but were not included in the earlier analyses. The youngest stand from which new data were available was 4.3 years and the oldest being 10.5 years. The models predicted well for the five plots tested (see Appendix 12a (i - v)). This means that the models are efficient for prediction purposes as from the age of 4.3 years or approximately as from the age of 4 years.

(ii) New stands of E. tereticornis

The models were tested on several plot data of the species at ages of 4.0-8.2 at Afaka and Kabama. For all the plot data tested, the models predicted well as from the age of 6.3 years (see Appendix 12b(i - vi)). The K-S test showed a significant difference between the predicted cumulative frequency distribution and the actual cumulative frequency distribution for one out of the six plots tested . This plot was established in a 4-year old plantation at Afaka. The models however

gave good predictions for the two plots tested at the age of 4.3 years at Kabama. This appears somehow interesting because the data at age 4.3 years at Kabama did not give a good fit to the Weibull distribution and were therefore not included for the construction of the models. Testing could not be carried out at age 5 since no plots had measurements at that age. In view of this, the minimum age at which the models might be regarded as efficient for prediction exercise is about 6 years.

(iii) New stands of P. caribaea

The Weibull parameter models were tested on new plot data of P. caribaea at ages 7.7 - 21.9 years in three of the study locations - Afaka, Nimbia and Miango - where new stand data could be obtained. When the K-S test was applied, there was no significant difference between the predicted and the actual cumulative diameter frequency distributions in the plots as from the age of about 10 years (see Appendix 12c(i - x)). Between the ages of 7.7 - 9.1 years for which data were also available, a significant difference existed between the predicted and the actual cumulative frequency distributions. Therefore,

the minimum age at which the models could be regarded as reliable for prediction purposes is about 10 years.

The Weibull parameter models have been tested in both experimental and new stands of the species and found suitable for application, though with some limitations regarding the minimum age limits as from which the models could give reliable predictions. Therefore, the composite model for estimating cumulative diameter distribution in the stands of the species is given by

$$F(X) = 1 - \exp\left\{-\left\{\frac{(X - a')}{b'}\right\}^{c'}\right\} \quad (50)$$

where a' , b' and c' represent the estimated Weibull parameters for each species.

6.2.4.3 Discussion

The Weibull distribution is capable of describing the diameter distribution in the stands of P. caribaea as from the minimum age of 5.7 years as

mentioned in Section 6.1.1 . However, the Weibull parameters could not be accurately predicted from the stand attributes of the species until the age of about 10 years. This follows that, in this regard, the Weibull distribution is acting as a growth function taking into consideration the exploitation of a certain minimum amount of the site growth potentials before giving an acceptable diameter prediction . E. cloeziana and E. tereticornis are faster growing species than P. caribaea (as revealed later in the text) and they are therefore capable of exploiting the site growth potentials faster than P. caribaea . Hence the Weibull parameter models gave acceptable diameter predictions at earlier ages than that of P. caribaea. Yang *et al* (1978) have also noted the potential of the Weibull-type functions as flexible growth curves although in their studies it was the height - age and the volume - age data that were modelled by the modified Weibull functions.

One common feature of the Weibull parameter models for each of the species is the ability to give

a better prediction of diameter distribution with increasing age. The results of the K-S test (Appendices 12(a - c)) show that the largest values of modulus (absolute difference) generally decrease with age for the three species. This further emphasises the importance of the Weibull as a growth function.

As discussed in Sections 2.2.2.1 and 5.2.1, the 'c' parameter is very important as it determines the shape of a distribution curve. A value of 'c' > 1 is said to result in a unimodal curve typical of the structure of an even-aged stand (Rustagi, 1978) . Therefore, the values of 'c' parameter for E. cloeziana (Table 6.2.4.1(a)) and E. tereticornis (Table 6.2.4.1(b)) confirmed that those data were from even-aged stands. The values of 'c' parameter for P. caribaea (Table 6.2.4.1(c)) showed some erratic cases where the values of 'c' were less than 1, and in fact, this was about 5% of the cases. This was however not significant enough to disagree with Rustagi (loc. cit.). A value of 'c' < 3.6 is said to result in a unimodal curve with a positive skewness while a value of

'c' > 3.6 is expected to generate negatively skewed curves. A normal distribution is expected to have a 'c' value of about 3.6 (Rustagi, loc. cit.). Positively skewed curves are therefore indicative of the presence of suppressed trees which survive in view of competition. Such a species is regarded as shade tolerant. On the other hand, a stand of a species having a negatively skewed curve contains little or no suppressed trees.

The application of the values of 'c' parameter in the description of shade tolerance of the species in this study is somehow difficult as some of the stands had been thinned at one time or the other. However, some interpretations can still be made especially when the data for both the thinned and unthinned stands of the species are examined.

With regard to E. cloeziana, most of the values of 'c' were greater than 3.6 (Table 6.2.4.1(a)) and this indicates negatively skewed distribution curves for most of the stands. This implies that E. cloeziana is not a shade tolerant species. In a few cases where the 'c' values were

less than 3.6, these were young stands where competition for light was not yet serious. Visual examination of the stands also confirmed this finding.

With reference to E. tereticornis, most of the 'c' values were also greater than 3.6 (Table 6.2.4.1(b)). Following Rustagi's observation, one is inclined to suggest that E. tereticornis is not a shade tolerant species. However, this is a bit questionable considering that measurement numbers 6 - 10 (Table 6.2.4.1(b)) which were from an unthinned plot at Kabama had nearly 100% survival despite competition and suppression within the period the five measurements were taken. The initial stocking in the plot referred to was 1166 trees per ha and a few of the trees missing during the subsequent measurements had been cut illegally. In actual fact, E. tereticornis is a shade tolerant species when raised in a pure stand of even spacing. In this fashion, the species seems to have the ability to redistribute the growth potentials almost evenly among the trees in such a way that the negative skewness was maintained with

increasing age. This implies that the standard deviation in diameters in such a stand will not be great and, on a probability density (frequency distribution) curve, most of the trees will have diameters close to the mean. In fact, the shade tolerant ability of the species has led to the initiation of the "coppice with standards" experiments that commenced at Zaria (Mohammed, 1976).

In the P. caribaea stands, about 70% of the values of 'c' parameter was less than 3.6 (Table 6.2.4.1(d)). In most of the stands, these values were actually less than 3.6 irrespective of whether these were thinned or unthinned stands. P. caribaea can therefore be regarded as a shade tolerant species. This finding is further supported by the permanent sample plot records of some unthinned plots in the spacing experiment of P. caribaea at Afaka. The records showed that some of these plots still maintained a stocking as high as 2,800 trees per ha with little or no mortality up to the age of 16 years.

6.3 Models for top height-age curves.

The model parameters or constants for the trial fitting of the top height - age curves (provisional average site index curves) for E. cloeziana, E. tereticornis and P. caribaea (Figs. 5.3(a - c)) are summarised in Tables 6.3(a & b) and Models (53) - (55) .

Comparing the three functions for fitting the top height - age curves (viz: the Gompertz, Logistic and the polynomial functions), except in the case of E. tereticornis where the log-polynomial function was used instead of the ordinary polynomial, all the functions gave almost the same top height figures within the age range of field data (see Figs. 5.3(a - c) and Tables 6.3(c - e)). With respect to E. cloeziana and P. caribaea, outside the range of field data, the Gompertz curves topped the trend and next to these were the Logistic curves while the polynomial curves showed a downward trend with increasing age (see Figs. 5.3(a) and 5.3(c)). With reference to E. tereticornis, the Gompertz and the Logistic

curves followed almost the same trend even outside the range of field data. The log-polynomial function started an upward exponential trend even within the range of field data (Fig. 5.3(b)).

From the fore-going discussion, it may be inferred that both the polynomial and the log-polynomial functions could not be described as suitable growth models in-spite of the fact that they had coefficients of multiple correlation and root mean square errors (RMSE) that were comparable with those obtained from the Gompertz and the Logistic functions (see Tables 6.3(a & b) and Models (53) - (55)). The Gompertz function gave slightly better fits (than the Logistic function) for the E. tereticornis and P. caribaea height - age data. The Gompertz function gave root mean square errors of 1.4840 for E. tereticornis and 1.3308 for P. caribaea while the Logistic function gave corresponding figures of 1.4939 and 1.3452 for the two species respectively. With regard to E. cloeziana, the Logistic function gave a slightly better fit (with RMSE of 1.3749) than the Gompertz function (with RMSE of 1.3918).

(i) Gompertz function

$$H_d = a_1 \cdot e^{-c(A - G)} \quad (51)$$

Table 6.3 (a) Gompertz parameters for top height-age curve for each of the three species.

Parameters estimated	<u>E. cloeziana</u>	<u>E. tereticornis</u>	<u>P. caribaea</u>
a_1	32.3500	25.1100	32.1700
c	0.1837	0.3576	0.0989
G^*	3.1540	2.5080	8.4120
r	0.9603	0.9150	0.9590
RMSE	1.3918	1.4840	1.3308

* Refers to age at maximum top height C.A.I.

H_d = Top height (m)

A = Age in years

e = Exponential constant (2.7183)

(ii) Logistic function

$$H_d = b_1 \left\{ 1 + e^{-b_2(A - b_3)} \right\}^{-1} \quad (52)$$

Table 6.3 (b) Logistic parameters for top height-age curve for each of the three species.

Parameters estimated	<u>E. cloeziana</u>	<u>E. tereticornis</u>	<u>P. caribaea</u>
b_1	30.9900	24.8900	29.1000
b_2	0.2540	0.4292	0.1616
b_3^*	4.8290	3.3920	10.8700
r	0.9612	0.9140	0.9580
RMSE	1.3749	1.4939	1.3452

* Refers to age at maximum top height C.A.I.

(iii) Polynomial function

E. cloeziana

$$H_d = 3.1840 + 2.95108A - 0.0830A^2 \quad (53)$$

$$R = 0.9607$$

$$RMSE = 1.3848$$

E. tereticornis

$$\begin{aligned} \text{Log}_e H_d = & 1.11695 + 0.56124A \\ & - 0.05278A^2 + 0.00167A^3 \end{aligned} \quad (54)$$

$$R = 0.9440$$

$$RMSE = 1.3626$$

P. caribaea

$$H_d = 1.5324 + 1.2660A - 0.0043A^3 \quad (55)$$

$$R = 0.9602$$

$$RMSE = 1.3110$$

Predicted top heights* for
E. gloeziana with the undermentioned
functions.

Age	Gompertz	Logistic	Polynomial
2	9.4	10.2	8.8
4	13.7	13.8	13.7
6	17.9	17.8	17.9
8	21.4	21.4	21.5
10	24.3	24.4	24.4
12	26.6	26.7	26.6
14	28.2	28.2	28.2
16	29.4	29.3	29.1

By extra- polation (18	30.3	29.9	29.4
(20	30.9	30.4	29.0
(22	31.4	30.6	28.7
(24	31.6	30.8	28.4

* All figures were computed from
Tables 6.3 (a & b) and Model(53)
See Fig. 5.3 (a) for graphical
presentation.

Table 6.3(d) Predicted top heights* for
E. tereticornis with the
undermentioned functions.

Age	Gompertz	Logistic	Log-polynomial
2	7.6	8.8	7.7
4	14.0	14.0	13.8
6	18.8	18.8	19.1
8	21.8	21.9	21.9
10	23.4	23.5	22.7
12	24.3	24.3	23.1
14	24.7	24.6	24.9
16	24.9	24.8	30.9

By extra- polation (18	25.0	24.8	47.7
(20	25.1	24.9	99.3
(22	25.1	24.9	302.7

* All figures were computed
from Tables 6.3 (a & b) and
Model (54). See Fig. 5.3(b).

Table 6.3 (e) Predicted top-heights* for P. caribaea with the under-mentioned functions.

Age	Gompertz	Logistic	Polynomial	
4	6.8	7.2	6.6	
6	9.0	9.1	9.0	
8	11.4	11.2	11.4	
10	13.7	13.5	13.8	
12	16.0	15.9	16.0	
14	18.1	18.2	18.1	
16	20.1	20.2	20.0	
18	21.8	22.1	21.8	
20	23.4	23.7	23.4	
22	24.8	25.0	24.8	
24	26.0	26.0	26.0	
26	27.0	26.8	26.9	
28	27.9	27.4	27.5	
<hr style="border-top: 1px dashed black;"/>				
By extrapolations.	30	28.6	27.8	27.9
	32	29.2	28.2	28.0
	34	29.7	28.4	27.7
	36	30.1	28.6	27.0
	38	30.5	28.7	26.0
	40	30.8	28.8	24.6

* All figures were computed from Tables 6.3 (a & b) and Model (55).
See also Fig.5.3(c).

6.3.1 Provisional site index curves

The constructed site index curve representing the average site class for each species is mainly provisional. Those for E. cloeziana and E. tereticornis lacked sufficient or adequate data points. The dispersion of data points in the case of E. cloeziana was not great (Fig. 5.3(a)), and more so as the species is only represented at Afaka where the site characteristics are fairly uniform, the likelihood that all the plots covered could fairly well belong to the same site class can not be ruled out. E. tereticornis has a wider dispersion in top height - age data (Fig. 5.3(b)) and as the species is widely planted all over the Guinea Savana Zone (Southern and Northern Guinea), there is likely to be at least three site classes (Adegbehin, 1978). The problem at present is that data were not available from all the locations where the species had been planted. P. caribaea had the greatest amount of height - age data (Fig. 5.3(c)) from the various study locations. Tentatively, three site classes were adequately represented by this species as will be seen later in the text.

6.4 Volume prediction

The most useful commercial quantitative parameter for measuring the yield in a forest stand is the volume production although this is less accurately estimated than the diameter figures or basal area growth. The prediction models constructed for each species include the stand volume model and models for the volume - age curves. The stand volume model considered the easily measured stand attributes (such as basal area of standing trees, number of standing trees, top height etc) as independent variables while the models for volume-age curves predicted total volume production from age with respect to the average site.

The standing volume gives an indication of the quantity of the growing stock while the total volume production gives an indication of site when a certain species is considered at a given age over a fairly wide area (nearly the same spacing or thinning regime assumed). The total volume production is also involved in the determination of the maximum mean annual increment (M.M.A.I) usually

obtained via the total volume production-age curve. The M.M.A.I itself plays an important role in the determination of a rotation age. In most cases, while the information on the total basal area production could be obtained, that of total volume production might not be available, but it might be possible to predict the latter from the former. It might even be possible to predict the total volume production from the standing volume which in turn might be predicted from some other stand variables. Hence a knowledge of the inter-correlations of the stand variables in this study is valuable.

6.4.1 Inter-correlations of the stand variables

Tables 6.4.1 (a - c) present the intercorrelations of the stand variables for the three species. The tables show that for E. cloeziana and E. tereticornis the total volume production (TV) was significantly correlated with all the other stand variables. For E. cloeziana, the highest correlation of TV was obtained with the standing volume, SV, ($r = 0.995$) while for E. tereticornis, TV had the

highest correlation of 0.984 with the total basal area production (TBA). In the case of P. caribaea, TV also had significant correlations with all the other stand parameters except the number of standing trees/ha (N); TV also had the highest correlation of 0.992 with SV.

In the E. cloeziana stands, the standing volume was significantly correlated with all the other stand parameters, the highest correlation being with TBA ($r = 0.996$) while E. tereticornis and P. caribaea had the standing volume significantly correlated with all the other stand parameters except the number of standing trees (N). For the latter two species, the standing volume had the highest correlation with TBA ($r = 0.975$ and 0.962 for E. tereticornis and P. caribaea respectively).

For both E. cloeziana and E. tereticornis, the total basal area production (TBA) was significantly correlated with all the other stand parameters. The TBA had the highest correlation with age in the E. cloeziana stands ($r = 0.978$) whereas it had the highest correlation with the mean

diameter of dominant trees, D_d , in the E. tereticornis stands ($r = 0.946$). In the case of P. caribaea, the TBA was significantly correlated with all the other stand variables except the number of standing trees, and the highest correlation was with the basal area of standing trees, BA, ($r = 0.970$) .

The basal area of standing trees (BA) was significantly correlated with all the other stand variables in the case of E. cloeziana and the highest correlation was with the mean diameter of dominant trees, D_d , ($r = 0.969$). With regard to E. tereticornis and P. caribaea, BA was significantly correlated with all the other stand variables except N. In the E. tereticornis stands, the BA had the highest correlation with age ($r = 0.832$) whereas it had the highest correlation with the quadratic mean diameter, D_q , ($r = 0.736$) in the P. caribaea stands.

Table 6.4.1 (a)

Inter-correlations of the stand variables for E. cloeziana

	TV	SV	TBA	BA	Age	Hd	MH	N	Dq	Dd
TV	1.000									
SV	0.995	1.000								
TBA	0.988	0.996	1.000							
BA	0.538	0.964	0.976	1.000						
Age	0.989	0.988	0.978	0.941	1.000					
Hd	0.961	0.966	0.974	0.943	0.944	1.000				
MH	0.967	0.966	0.963	0.923	0.947	0.995	1.000			
N	0.836	0.804	0.793	0.660	0.793	0.799	0.827	1.000		
Dq	0.987	0.987	0.990	0.947	0.974	0.982	0.982	0.952	1.000	
Dd	0.958	0.971	0.983	0.969	0.948	0.983	0.973	0.779	0.979	1.000

SIGNIFICANCE LEVELS (PROBABILITIES OF NO CORRELATION)

	TV	SV	TBA	BA	Age	Hd	MH	N	Dq	Dd
TV	0.000									
SV	0.000	0.000								
TBA	0.000	0.000	0.000							
BA	0.000	0.000	0.000	0.000						
Age	0.000	0.000	0.000	0.000	0.000					
Hd	0.000	0.000	0.000	0.000	0.000	0.000				
MH	0.000	0.000	0.000	0.000	0.000	0.000	0.000			
N	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000		
Dq	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Dd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

CLOEZIANA STAND DATA

SELECT 'ALL'

15 CASES.

Table 6.4.1 (b) Inter-correlations of the stand variables for E. tereticornis

	TV	SV	TBA	BA	Age	Hd	MH	N	Dq	Dd
TV	1.000									
SV	0.979	1.000								
TBA	0.984	0.975	1.000							
BA	0.903	0.962	0.937	1.000						
Age	0.941	0.921	0.918	0.832	1.000					
Hd	0.817	0.781	0.767	0.665	0.890	1.000				
MH	0.873	0.801	0.814	0.640	0.918	0.926	1.000			
N	0.348	0.175	0.304	0.037	0.331	0.324	0.554	1.000		
Dq	0.890	0.793	0.867	0.651	0.852	0.751	0.903	0.699	1.000	
Dd	0.960	0.905	0.946	0.816	0.913	0.836	0.881	0.448	0.929	1.000

SIGNIFICANCE LEVELS (PROBABILITIES OF NO CORRELATION)

	TV	SV	TBA	BA	Age	Hd	MH	N	Dq	Dd
TV	0.000									
SV	0.000	0.000								
TBA	0.000	0.000	0.000							
BA	0.000	0.000	0.000	0.000						
Age	0.000	0.000	0.000	0.000	0.000					
Hd	0.000	0.000	0.000	0.000	0.000	0.000				
MH	0.000	0.000	0.000	0.000	0.000	0.000	0.000			
N	0.025	0.168	0.045	0.420	0.031	0.035	0.000	0.000		
Dq	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Dd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000

STAND DATA FOR TERETICORNIS
SELECT 'ALL'
32 CASES.

Table 6.4.1(c)

Inter-correlations of the stand
variables for P. caribaea

	TV	SV	TBA	BA	Age	Hd	MH	N	Dq	Dd
TV	1.000									
SV	0.992	1.000								
TBA	0.969	0.962	1.000							
BA	0.943	0.961	0.970	1.000						
Age	0.705	0.730	0.646	0.640	1.000					
Hd	0.733	0.746	0.651	0.621	0.930	1.000				
MH	0.718	0.728	0.630	0.598	0.929	0.983	1.000			
N	0.083	0.050	0.103	0.188	0.239	0.341	0.364	1.000		
Dq	0.865	0.864	0.762	0.736	0.808	0.861	0.874	0.461	1.000	
Dd	0.830	0.840	0.710	0.717	0.777	0.816	0.822	0.450	0.962	1.000

SIGNIFICANCE LEVELS (PROBABILITIES OF NO CORRELATION)

	TV	SV	TBA	BA	Age	Hd	MH	N	Dq	Dd
TV	0.000									
SV	0.000	0.000								
TBA	0.000	0.000	0.000							
BA	0.000	0.000	0.000	0.000						
Age	0.000	0.000	0.000	0.000	0.000					
Hd	0.000	0.000	0.000	0.000	0.000	0.000				
MH	0.000	0.000	0.000	0.000	0.000	0.000	0.000			
N	0.275	0.358	0.227	0.085	0.040	0.005	0.003	0.000		
Dq	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Dd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

VOL DATA CARIBAEA
SELECT 'ALL'
54 CASES.

Generally, it has been found that the stand variables were highly correlated with each other. For the three species covered, only low thinning was carried out in most of the stands. Further data processing outside the scope of this text has shown that the total volume production, for example, can be estimated from the total basal area production or from the standing volume by simple linear functions with a good degree of accuracy (under the assumption of the low thinning regime). The results of the inter-correlations of the stand variables can therefore be very useful in yield studies in other plantations of similar characteristics. Furthermore, while the results obtained open a new avenue for further growth studies of the species, they have also served as a first step in the determination of the stand volume model for each of the species.

6.4.2 Stand volume models

The best models for predicting the standing volume (SV) from the stand variables are as follows:

(i) E. cloeziana

$$\begin{aligned}
 SV = & 181.2164 - 0.7097N \\
 & + 0.000386N^2 + 0.3170BA^2 \\
 & + 80.2807HR - 10.4569HR^2 \quad (56)
 \end{aligned}$$

$$\begin{aligned}
 R & = 0.9995 \\
 DWST & = 2.1797 \\
 RMSE & = 2.2486 \text{ m}^3/\text{ha}
 \end{aligned}$$

where:

SV = Standing volume (m^3/ha)

HR = H_d/A

N = Number of standing trees/ha

BA = Basal area of standing trees (m^2/ha)

H_d = Top height (m)

(ii) E. tereticornis

$$\begin{aligned}
 SV = & - 155.6204 + 7.3763BA \\
 & + 0.3803BA^3 - 0.02553N \\
 & + 83.6559HR - 11.7117HR^2 \quad (57)
 \end{aligned}$$

$$\begin{aligned}
 R & = 0.9961 \\
 DWST & = 1.3261 \\
 RMSE & = 4.7057 \text{ m}^3/\text{ha}
 \end{aligned}$$

(iii) P. caribaea

$$\begin{aligned} SV &= - 12.4361 + 3.5464BA \\ &- 0.01585N + 0.1586BAH \\ &+ 36.5464BADN \end{aligned} \quad (58)$$

$$R = 0.99668$$

$$DWST = 1.9591$$

$$RMSE = 10.11 \text{ m}^3/\text{ha}$$

where:

$$BAH = BA \times H_d$$

$$BADN = (BA \times D_d)/N$$

D_d = Mean diameter of dominant trees.

All independent variables were significant at least up to 5% level.

Generally, the stand volume models predict the standing volumes independent of site classification since top height (H_d) and age or top height/age served as independent variables in the models. Other obvious independent variables considered in the models were basal area of standing trees (BA) and

the number of standing trees (N). With regard to E. tereticornis and P. caribaea, although Tables 6.4.1 (b & c) tend to show that the number of standing trees/ha was not significantly correlated with the standing volume, it became significant when included in each of the models for the two species. As the stand volume model varies from one species to another, the model for each species will be discussed separately.

(i) E. cloeziana

The main explanatory variables in the stand volume model for E. cloeziana were the basal area of standing trees, number of trees/ha and top height/age which served as a site factor. When the constructed model was tested on the original 15 sets of data from the stands of the species at Afaka, the predicted standing volumes were very close to the observed standing volumes (see Fig. 6.4.2 and Appendix 11(a)). A comparison of the deviation between the two sets of volume figures gave a very low value of RMSE of $2.249 \text{ m}^3/\text{ha}$.

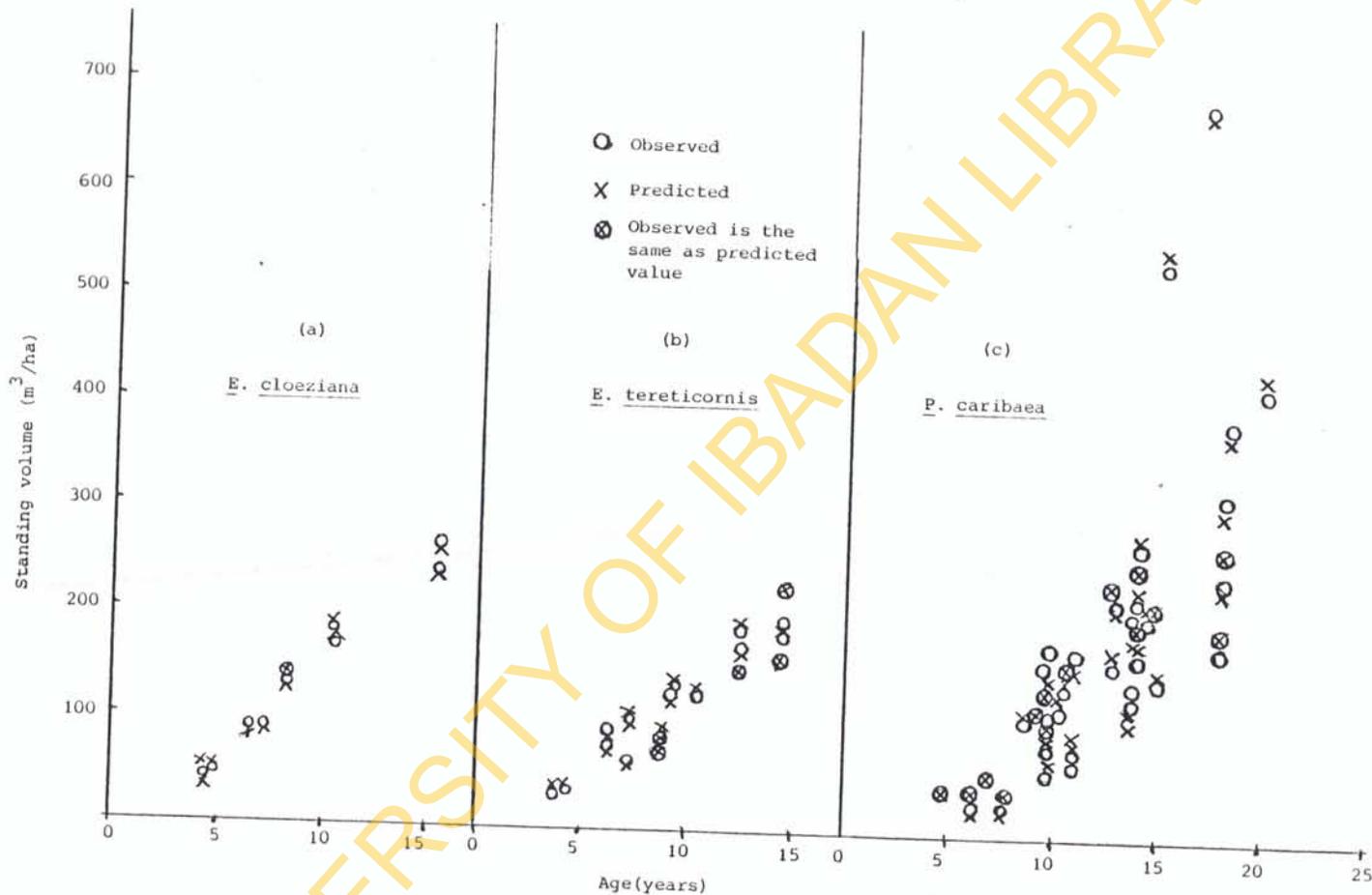


Fig. 6.4.2

Comparisons of the observed and predicted standing volumes for E. cloeziana, E. tereticornis and P. caribaea.
 (See volume figures in Appendices 11(a-c).

(ii) E. tereticornis

The stand volume model for E. tereticornis included the same independent variables as that of E. cloeziana except that age became an additional explanatory variable in the model. The model also gave good predictions when tested on the original 23 sets of data (Fig. 6.4.2 and Appendix 11(b)), but with a higher value of RMSE of about 4.706 m³/ha.

(iii) P. caribaea

As in E. cloeziana and E. tereticornis, the stand volume model for P. caribaea included the basal area and number of standing trees. Additional explanatory variables included in the model were some combinations of the stand attributes such as $BA \times H_d$ and $(BA \times D_d)/N$. On testing the model on the original 54 sets of data at the various study locations, the predicted standing volumes were also statistically close to the observed volumes

(Fig. 6.4.2 and Appendix 11(c)), but with an RMSE of $10.11 \text{ m}^3/\text{ha}$. However, this value of RMSE can not be said to be too great, considering the range of field data which included standing volumes of $30 - 700 \text{ m}^3/\text{ha}$ over the different geographical locations.

It is also of interest to note that, unlike the stand volume model for E. tereticornis, age was not a significant explanatory variable in the P. caribaea model. In spite of this, the model predicted well for young stands where the standing volumes were small as well as for older stands where the standing volumes were large (see Appendix 11(c)). Moreover, unlike the Weibull parameter predictive models for the same species, the stand volume model performed creditably well even for stands as young as 4.7 years.

6.4.2.1 Testing of stand volume models in plots

In order to carry out the model testing exercise, volume data were collected from new

plots of each species or from plots not included in the earlier regression analyses. New plot data of E. cloeziana were somehow few ; only 4 new plot data were obtained between the ages of 4.3 - 10.25 years. There were 11 new plot data of E. tereticornis with ages from 3.7 to 14.5 years and 14 new plot data of P. caribaea with ages between 6.5 to 21.9 years. It was only one plot of P. caribaea at the age of 21.9 years at Miango that had volume data outside the age range of experimental data.

In testing the models for each species, standing volume in each of the new plots was calculated based on the volume-basal area equation for each plot and 4 cm - diameter grouping as described in Section 5.4. The standing volume in each new plot was then predicted using the stand volume model developed for each species with the explanatory variables serving as input. The calculated standing volumes (i.e. the observed) and the predicted standing volumes were analysed for significant differences using the Chi-square goodness of fit testing procedure. The results of

the tests (Tables 6.4.2.1(a - c)) showed that there was no significant difference between the observed and the predicted standing volumes for each of the species.

With respect to the age range for which the stand volume model for each species might be regarded as reliable, each model is efficient for prediction within the age range of field data, i.e. between the ages of 4.2 to 15.5 years, 3.7 to 14.5 and 4.7 to 20.1 years for E. cloeziana, E. tereticornis and P. caribaea respectively. It is however possible that reliable results can be obtained if any of the models is used outside the range of field data, but enough precautionary measures should be taken when a situation like this arises.

Table 6.4.2.1(a) Observed and predicted standing volumes¹⁾ for E. cloeziana based on data from new stands

Stand No.	Age (Yrs)	Standing number of trees/ha	B.A. (m ² /ha)	H _d (m)	Standing Volume (m ³ /ha)	
					Observed	Predicted
1	4.3	769	11.9	11.9	36.1	37.6
2	6.0	914	16.1	18.1	86.1	83.5
3	10.25	831	24.0	27.2	178.5	180.3
4	10.25	861	22.3	26.0	147.4	150.7

- 1) Calculated Chi-square between the observed and predicted standing volumes = 0.2311 and the tabular $\chi^2_{0.05}$ with 3 degrees of freedom = 7.82 ; N.s

Table 6.4.2.1(b) Observed and predicted standing volumes¹⁾ for E. tereticornis using data from new stands.

Stand No.	Age (Yrs)	Standing number of trees/ha	B.A. (m ² /ha)	Top Height (m)	Standing Volume (m ³ /ha)	
					Observed	Predicted
1	3.7	1294	11.8	16.1	43.6	45.8
2	7.1	1220	19.4	19.0	112.6	115.8
3	10.5	815	21.4	23.5	153.7	151.9
4	12.5	815	24.9	24.2	190.6	184.7
5	14.5	815	27.5	25.1	220.4	216.1
6	4.0	1103	8.0	13.2	24.2	29.8
7	6.2	1103	13.1	17.5	74.6	70.3
8	8.2	880	13.8	22.6	91.1	90.9
9	4.0	1001	10.1	13.1	43.1	47.8
10	6.2	1020	15.0	19.4	95.7	90.7
11	8.2	784	15.9	24.7	114.2	112.9

- 1) Calculated Chi-square between the observed and predicted standing volumes = 2.5579 and the tabular $\chi^2_{0.05}$ with 10 degrees of freedom = 18.31 ; N.s

Table 6.4.2.1(c) Observed and predicted standing volumes¹⁾
for P. caribaea using data from new stands

Stand No.	Age (Yrs)	Standing number of trees/ha	B.A. (m ² /ha)	H _d (m)	D _d (cm)	Standing Volume (m ³ /ha)	
						Observed	Predicted
1	6.5	1122	13.9	11.5	14.9	52.6	51.2
2	7.9	1136	20.3	12.2	18.2	94.9	92.7
3	10.1	1080	25.7	13.6	20.5	133.4	134.9
4	7.7	1592	15.6	10.7	15.9	45.9	49.8
5	10.2	1471	25.4	13.7	20.9	114.4	122.7
6	12.0	1080	27.4	14.7	22.6	153.9	152.5
7	12.0	983	27.6	15.4	23.5	170.4	161.4
8	12.0	1107	26.5	14.3	21.4	155.4	142.8
9	15.0	1111	26.1	16.7	25.3	150.3	153.7
10	15.0	781	17.1	15.6	20.9	101.9	99.1
11	15.0	931	25.0	18.4	24.3	146.0	158.3
12	15.0	1141	26.8	16.2	25.1	150.9	154.9
13	18.0	1246	47.1	19.1	25.6	329.0	312.9
14	21.9	817	53.5	28.0	35.6	508.0	487.2

1) Calculated Chi-square between the observed and predicted standing volumes = 5.5301 and the tabular $\chi^2_{0.05}$ with 13 degrees of freedom = 22.36 ; N.s

6.4.3 Models for total volume production - age curves.

The total volume production can be predicted from several stand variables. However, when the model for total volume production considers only age as the independent variable, there is the additional advantage of determining the volume production at various ages and also the maximum mean annual increment (M.M.A.I.) which serves as a guide in fixing a rotation age. The trial fittings of the average total volume production-age curve for each species were carried out using the Gompertz and the Logistic functions.

The model parameters for trial fittings of the curves for E. cloeziana and E. tereticornis (Figs. 5.4.2(a & b) and P. caribaea (Fig. 5.4.2.1, Gompertz A and Logistic A curves for the original data) have been summarised in Tables 6.4.3(a & b). For the final construction of the total volume production - age curve for the assumed unthinned stand of P. caribaea at an average site (Section 5.4.2.1), the Gompertz and the Logistic functions

were used to model the volume - age figures in Table 5.4.2.1 (to give the Gompertz B and Logistic B curves in Fig. 5.4.2.1). Table 6.4.3(c) shows the estimated parameters for the two functions.

(a) Gompertz function

$$TV = a_1 \cdot e^{-e^{-c(A - G)}} \quad (59)$$

Table 6.4.3(a) Gompertz parameters for volume-age curve for each of the three species.

Parameters estimated	<u>E.cloezi</u> ana	<u>E.tereticornis</u>	<u>P.caribaea</u>
a ₁	372.2400	496.1000	1311.6000
c	0.1835	0.0940	0.0856
G*	8.4570	13.0000	20.3000
r	0.9913	0.9430	0.7140
RMSE	11.3500	19.7000	110.0000
TV at M.C.A.I**	136.9000	182.5000	482.5000

* Age at Maximum current annual increment (years)

** Total volume at M.C.A.I (in m³/ha/yr) = a₁/e

(b) Logistic function

$$TV = b_1 \left\{ 1 + e^{-b_2(A - b_3)} \right\}^{-1} \quad (60)$$

Table 6.4.3(b) Logistic parameters for volume-age curve for each of the three species.

Parameters estimated	<u>E.cloeziانا</u>	<u>E.tereticornis</u>	<u>P.caribaea</u>
b_1	313.5000	310.0000	636.5000
b_2	0.3505	0.2250	0.2461
b_3^*	9.2650	11.4000	16.1700
r	0.9908	0.9420	0.7140
RMSE	11.7000	19.8000	110.0000
TV at M.C.A.I**	156.8000	155.0000	318.2000

* Age at M.C.A.I (years)

** Total volume at M.C.A.I = $0.5 \times b_1$

Table 6.4.3(c) Gompertz and Logistic parameters for volume-age curve for an assumed unthinned P. caribaea stand

Gompertz function ¹⁾		Logistic function ²⁾	
Parameters estimated	Value	Parameters estimated	Value
a_1	1058.0000	b_1	932.8000
c	0.0985	b_2	0.1644
G	19.2800	b_3	21.7700
r	0.9996	r	0.9994
RMSE	9.4300	RMSE	11.4700
TV at M.C.A.I	389.2000	TV at M.C.A.I	466.4000

1) Parameters have the same interpretations as for Table 6.4.3(a)

2) Parameters have the same interpretations as for Table 6.4.3(b)

With regard to E. cloeziana and E. tereticornis, the Gompertz and the Logistic curves did not deviate very much within the age range of field data (see Figs. 5.4.2(a & b) and Tables 6.4.3(d & e)). However, outside the range of field data, the Gompertz curve gave comparatively higher volume figures (but with lower root mean square error) than the Logistic curve. This same trend was reflected in the volume-age curves for P. caribaea where the curve, Gompertz A and the curve, Logistic A, were fairly well in agreement up to the age of 20 years covered by the field data and after this, the Logistic A curve fell below the Gompertz A curve (Fig. 5.4.2.1 and Table 6.4.3(f)). The Gompertz B and the Logistic B curves obtained from an assumed unthinned stand of P. caribaea on an average site (Fig. 5.4.2.1 and Table 6.4.3(g)) were expected to have the same or almost the same trend since the total volume - age data in Table 5.4.2.1 were based on models (39) and (40) which were smooth functions. However, the Logistic B

curve (with a higher root mean square error of 11.47) still fell below the Gompertz B curve (with a lower root mean square error of 9.43). This is in agreement with the finding of Yang et al.(1978) that the Gompertz function is generally superior to the Logistic.

Table 6.4.3(d) Predicted total volume production figures* (m^3/ha) for E. cloeziana based on the Gompertz and Logistic functions.

Age (Yrs)	Gompertz ¹			Logistic ²		
	(m^3/ha).	M.A.I	C.A.I	(m^3/ha)	M.A.I	C.A.I
4	38.6	9.6	19.4	42.8	10.7	16.4
6	77.5	12.9	23.8	75.7	12.6	23.4
8	125.2	15.6	25.0	122.6	15.3	27.2
10	175.2	17.5	22.8	176.9	17.7	24.8
12	220.9	18.4	19.2	226.6	18.9	18.4
14	259.3	18.5	15.2	263.4	18.8	11.6
16	289.8	18.1	13.6	286.5	17.9	6.5
18	312.9	17.3	8.6	299.5	16.6	3.4
20	330.1	16.5	6.2	306.4	15.3	2.0
22	342.5	15.6	4.4	310.0	14.1	0.9
24	351.4	14.6		311.8	13.0	

* Figures represent the average site class.

1) Figures computed from Model(59) and Table 6.4.3(a).

2) Figures computed from Model (60) and Table 6.4.3(b).

Table 6.4.3 (e)

Predicted total volume production figures* (in m^3/ha) for E. tereticornis based on the Gompertz and the Logistic functions.

Age (Yrs)	Gompertz ¹⁾			Logistic ²⁾		
	m^3/ha	M.A.I	C.A.I	m^3/ha	M.A.I	C.A.I
4	47.9	12.0	11.8	49.5	12.4	10.8
6	71.5	11.9	14.0	71.1	11.8	13.8
8	99.6	12.4	15.8	98.6	12.3	16.2
10	131.2	13.1	16.8	131.0	13.1	17.4
12	164.7	13.7	17.2	165.7	13.8	16.8
14	199.0	14.2	16.8	199.3	14.2	14.8
16	232.7	14.5	16.1	229.0	14.3	12.0
18	264.9	14.7	15.0	253.0	14.1	9.1
20	295.0	14.8	13.8	271.2	13.6	6.5
22	322.5	14.7	12.4	284.2	12.9	4.5
24	347.2	14.5	11.0	293.2	12.2	3.0
26	369.1	14.2	9.6	299.2	11.5	2.0
28	388.3	13.9	8.3	303.2	10.8	1.3
30	404.9	13.5		305.8	10.2	

By
Extrapolations

* Figures represent the average site class

- 1) Figures computed from Model(59) and Table 6.4.3(a).
- 2) Figures computed from Model(60) and Table 6.4.3(b).

Table 6.4.3(f) Predicted total volume production figures* for P. caribaea (with the original data) based on the Gompertz and Logistic functions.

(Yrs.)	Gompertz (1)			Logistic (2)		
	(m ³ /ha)	M.A.I.	C.A.I.	(m ³ /ha)	M.A.I.	C.A.I.
4	22.9	5.7		30.4	7.6	
6	43.3	7.2	10.2	48.2	8.0	8.9
8	74.1	9.3	15.4	75.2	9.4	13.5
10	116.5	11.5	21.2	114.4	11.4	19.6
12	170.5	14.2	27.0	168.0	14.0	25.8
14	235.0	16.8	32.2	235.5	16.8	33.6
16	307.9	19.2	36.4	311.7	19.5	38.2
18	386.8	21.5	39.4	388.8	21.6	38.6
20	468.7	23.4	41.0	458.1	22.9	34.6
22	551.0	25.0	41.2	514.1	23.4	28.0
24	631.6	26.3	40.3	555.6	23.2	20.8
26	708.5	27.2	38.4	584.5	22.5	14.4
28	780.6	27.9	36.0	603.6	21.6	9.6
30	847.0	28.2	33.2	616.0	20.5	6.2
32	907.3	28.4	30.2	623.8	19.5	3.9
34	961.4	28.3	27.0	628.7	18.5	2.4
36	1009.6	28.0	24.1	631.7	17.5	1.5
38	1052.0	27.7	21.2	633.5	16.7	0.9
40	1089.1	27.2	18.6	634.7	15.9	0.6

* Figures represent the average site class and both M.A.I and C.A.I are in m³/ha/yr.

- 1) Figures computed from Model (59) and Table 6.4.3(a)
(r = 0.714).
- 2) Figures computed from Model (60) and Table 6.4.3(b)
(r = 0.714).

Table 6.4.3(g) Predicted total volume production figures* for *P. caribaea* (from an assumed unthinned stand) based on the Gompertz and Logistic functions.

Age (Yrs.)	Gompertz ¹⁾			Logistic ²⁾		
	(m ³ /ha)	M.A.I.	C.A.I.	(m ³ /ha)	M.A.I.	C.A.I.
4	19.3	4.8	9.1	47.7	11.9	8.6
6	37.5	6.2	13.9	65.0	10.8	11.4
8	65.3	8.2	19.2	87.9	11.0	15.0
10	103.7	10.4	24.4	117.8	11.8	19.1
12	152.6	12.7	29.0	156.0	13.0	23.8
14	210.5	15.0	32.4	203.5	14.5	28.6
16	275.3	17.2	34.5	260.6	16.3	33.0
18	344.3	19.1	35.3	326.5	18.1	36.4
20	414.9	20.7	35.3	399.2	20.0	38.1
22	484.8	22.0	35.0	475.4	21.6	37.8
24	551.9	23.0	31.6	551.1	23.0	35.7
26	615.0	23.6	29.0	622.5	23.9	32.0
28	673.0	24.0	26.3	686.5	24.5	27.4
30	725.6	24.2	23.4	741.3	24.7	22.6
32	772.5	24.1	20.8	786.6	24.6	18.0
34	814.0	23.9	18.2	822.7	24.2	14.1
36	850.3	23.6	15.8	850.9	23.6	10.7
38	881.8	23.2	13.6	872.3	23.0	8.1
40	908.9	22.7		888.5	22.0	

* Figures represent the average site class and both M.A.I and C.A.I. are in m³/ha/yr .

- 1) Figures computed from Model (59) and Table 6.4.3(c) ($r = 0.9996$).
- 2) Figures computed from Model (60) and Table 6.4.3(c) ($r = 0.9994$).

6.4.3.1 C.A.I and M.A.I for the average site

Although most of the data from the three species dealt with were from young stands and the points of culmination of the M.A.I , in particular, were located in the extrapolated regions of the curves, it is still worthwhile to discuss the 'expected' ages and volumes at which the culmination of growth takes place. This is a very important issue as this may give a hint as to what may be expected as the approximate optimum rotation period for each of the species. Comparing the growth figures from the Gompertz function which generally gave better fits to the volume-age data for the three species, tentatively, it may be said that the C.A.I reaches its peak at the ages of about 8.5 years for E. cloeziana, 13 years for E. tereticornis and 19.3 years for P. caribaea¹⁾ with the total volume production of about 137, 182 and 389 m³/ha respectively (Table 6.4.3.1)..

1) Refers to P. caribaea growth figures from the assumed unthinned stand (Gompertz B curve) which is close to an ideal situation.

Table 6.4.3.1

Ages at which C.A.I. and M.A.I. reach the peaks and their associated volumes for the average site class.

Species	Age (in yrs.) at which increment reaches peak		Total volume production (m ³ /ha) at peak of increment	
	C.A.I.	M.A.I. ⁽¹⁾	C.A.I.	M.A.I. ⁽¹⁾
<u>E. cloeziana</u>				
Gompertz function	8.5	13.4	136.9	240.0
Logistic function	9.3	12.0	156.8	228.0
<u>E. tereticornis</u>				
Gompertz function	13.0	19.4*	182.5	286.0*
Logistic function	11.4	16.0	155.0	234.0*
<u>P. caribaea</u>				
Gompertz function A ⁽²⁾	20.3	32.2*	482.5*	910.0*
Gompertz function B ⁽³⁾	19.3	30.3*	389.2	726.0*
Logistic function A ⁽²⁾	16.2	23.2*	318.2	540.0*
Logistic function B ⁽³⁾	21.8*	28.2*	466.4*	690.0*

* Figures obtained by extrapolations

- 1) M.A.I. figures (both age and volume) are given at the tangent point to the growth curve by a line passing through the origin (Figs. 5.4.2(a & b) and Fig. 5.4.2.1)) while the C.A.I. figures comes from Tables 6.4.3(a - c).
- 2) Based on the actual field data at various stockings.
- 3) Based on the assumed unthinned stand at an average site with an initial stocking of 1,200 stems/ha (see Table 5.4.2.1).

Similarly, the M.A.I is anticipated to reach its peak at the ages of 13.4 years for E. cloeziana, 19.4 years for E. tereticornis and 30.3 years for P. caribaea with the total volume production of 240, 286 and 726 m³/ha for the three species respectively.

There were great differences in total volume production obtained at the peak of increment for P. caribaea when the results from Gompertz A and Gompertz B curves were compared (Table 6.4.3.1). A similar pattern was shown by the results from the Logistic A and Logistic B curves. The results from Gompertz A and Logistic A curves, as earlier mentioned, were obtained from computations based on varying densities (Section 5.4.2.1) . The stocking ranged from 728 - 3281 stems per ha. The results from the Gompertz B and Logistic B curves, on the other hand, were obtained from an assumed unthinned stand at an average site with an ideal stocking of 1,200 stems per ha giving an allowance for mortality from year to year. Actually, the initial stocking of 1,200 stems per ha represents

the average survival at establishment with an initial spacing of 2.7 m by 2.7 m which is now commonly used. It is somehow difficult for one to make any valid conclusion about the differences in the total volume production at the peak of M.A.I due to the fact that the ages of culmination themselves lie in the extrapolated regions of the curves. However, it appears that the results from the Gompertz B and Logistic B curves are more realistic. It can be said that the curves, Gompertz A and Logistic A, gave poor fits to the data because of great variation in stocking, a situation noted by Smith and Kozak (1984). Moreover, as the Gompertz function generally gives a better prediction than the Logistic (Yang et al., 1978), the results from the Gompertz B curve are likely to be more reliable. Hence for P. caribaea, on discussing the ages and volumes at the culmination of the C.A.I and M.A.I, the Gompertz B figures have been quoted.

Still with reference to the assumed unthinned stand (Section 5.4.2.1), if there had been enough data on the basal areas and number of trees thinned

at the various ages, it could have been possible to introduce a standard thinning regime as from the age of 12 years. This will reduce the stocking to certain numbers most suitable for optimum volume production at the various ages. This implies that the quadratic mean diameters would have been higher than what were obtained (in Table 5.4.2.1) especially as from the age of 12 years.

6.5 General discussion

This section covers the discussion of the growth patterns of the three species, the rotation age and the site index reference age for each of the species. Provisional site classes for P. caribaea, the species with the greatest coverage in terms of study areas and field data (especially top height - age data), are also discussed.

i) Growth patterns of the species

With reference to the total volume production-age curve for the average site for each

species, E. cloeziana tends to have a faster initial growth rate than E. tereticornis while the latter has a higher initial growth rate than P. caribaea (Fig. 6.5). However, with increasing age, E. tereticornis gives comparatively higher volume figures than E. cloeziana while P. caribaea gives higher volume figures than E. tereticornis. This then implies that P. caribaea is naturally a longer rotation species than E. tereticornis which itself is a longer rotation species than E. cloeziana.

ii) Rotation age

The rotation age of a species depends on so many factors such as the uses of the trees, e.g. for poles, pulp and paper, sawnwood, site quality aspects, some technical aspects of management and economic considerations. In the case of Eucalyptus plantations in Kaduna State, they are being managed mainly for the production of poles though in some areas the long term objective of raising the plantations for sawnwood has been envisaged.

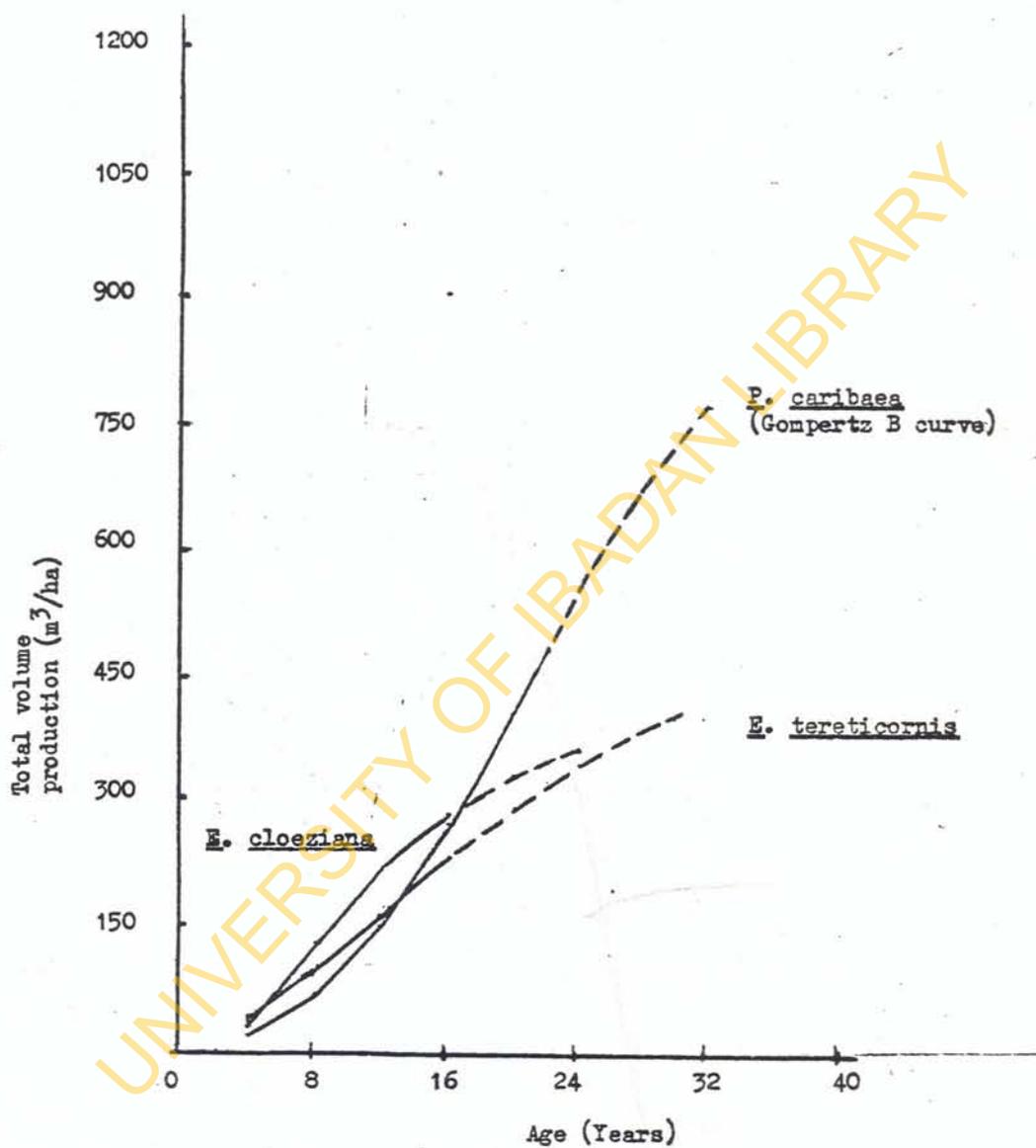


Fig. 6.5 Comparison of total volume production - age curves (based on the Gompertz function) for *E. cloeziana*, *E. tereticornis* and *P. caribaea*

At present, a system of "coppice with standards" is being experimented upon. This is to cater for the short-term objective of pole production and the long term objective of timber production. With regard to the pines, they are raised for pulp, paper production and sawnwood. When the emphasis of establishing a plantation is on the production of sawnwood, then it is desirable to determine its optimum rotation age in terms of volume production. However, the age of optimum volume production in a plantation may not necessarily be the same as the age of optimum economic returns from the same plantation, but the former will serve as a guide to the forest owner in managing his resources.

It has been mentioned that, on the average site, the M.A.I is anticipated to reach its peak at the ages of 13.4, 19.4 and 30.3 years for E. cloeziana, E. tereticornis and P. caribaea respectively (Section 6.4.3.1). With reference to eucalypts in general, the age at which the M.A.I reaches its maximum lies between 8 and 20 years although there are some extreme cases (Anon, 1979). For P. caribaea, the age at which the M.A.I

reaches its peak also varies to some extent.

Lackhan(1972) gave a range of 25 - 30 years for P. caribaea grown in Trinidad, depending on site quality. Luckhoff(1964) reported that the M.A.I reached its peak at the age of 33 years in Zululand (South Africa). The results so far obtained lie within the range expressed by these authors.

Generally, the rotation age could be 2 - 6 years above the age at which the M.A.I is falling. Therefore, from volume increment point of view, tentatively, E. cloeziana can have a rotation of about 19 years when considered for sawnwood while E. tereticornis may have a rotation of about 23 years on an average site. These figures may be considered as realistic since a 19-year old plantation of E. grandis at Ngoroge in Gongola State was proposed for clear-felling for sawnwood (Anon,1982). P. caribaea may have a rotation of about 32 years. Lamb(1973) reported a rotation of 23 - 32 years for P. caribaea plantations located at Drasa and Seaqqa in Fiji. However, the fact that Luckhoff(loc. cit.) reported that the M.A.I culminated around 33 years at Zululand implies that it is

possible to have a rotation higher than 32 years. The top height figures for the constructed average provisional site index curve also compare well with those of site class IV of the site index curves for P. patula at Sao-Hill (Southern Tanzania) where a rotation age of 30 - 35 years had been recommended (Adegbehin, 1982). This further gives a hint regarding the 'expected' rotation age for P. caribaea.

iii) Site index reference ages for the species

Fixing a site index reference age is very essential in order to specifically describe a site index curve. Generally, the reference age is fixed when the majority of the site growth potentials should have been utilized by a species. According to the recommendations by Carron (1968), the site index reference age of a species should be approximately two-third ($2/3$) of its rotation age. Therefore, a longer rotation species will have a higher site index reference age than a shorter rotation species.

Since the rotation age stated for each species is tentative, the site index reference age can be provisionally 13, 15 and 20 years for E. cloeziana, E. tereticornis and P. caribaea respectively. This means that for the average site class a top height of 27.4 m is attained at a reference age of 13 years for E. cloeziana based on the Logistic function (Table 6.3(c)) ; a top height of 24.8 m is attained at a reference age of 15 years for E. tereticornis (Gompertz function, Table 6.3(d)) while a top height of 23.4 m is reached at the age of 20 years for P. caribaea (Gompertz function, Table 6.3(e)).

iv) Provisional site classes for P. caribaea

Although P. caribaea did not have many data points above the age of 20 years, the provisional average site index curve may not differ very much from the 'expected' average site index curve. This is due to the availability of several top height - age data up to the age of 18 years (Fig. 5.3(c)) from the various study locations. Starting with the

site index for the average site class (23.4 m at age 20 years) and fixing the other site classes at 3 m intervals at the reference age of 20 years, the following three provisional site classes in Table 6.5(a) may be obtained.

Table 6.5(a) Provisional site classes for P. caribaea at a reference age of 20 years

	Class mid-point (m)	Class interval (m)
Site class I	26.4	24.9 - 27.9
Site class II (Average site class)	23.4	21.9 - 24.9
Site class III	20.4	18.9 - 21.9

At present, only two of the plots have reached or passed 20 years of age. According to the above classification, only the P. caribaea stand planted at Miango in 1961 falls in site class I (attaining a top height of 25.6 m at age 20) while the plot at Vom planted in 1954 falls in site II (with a top height of 23.4 m at age 20). Most of the other plots though still young are likely to lie

between the provisional site classes II and III.

The figures for the provisional site classes for P. caribaea (Table 6.5(a)) compare favourably with the results of the site index curves obtained for the same species at Trinidad and Tobago (Lackhan, 1972). The three "height classes" (site classes) constructed for the species by Lackhan (loc. cit.) also had a site index reference age of 20 years. Table 6.5(b) shows that the height figures for the two sets of classes are actually very close.

Table 6.5(b) Comparisons* of "height class" figures for P. caribaea at Trinidad and Tobago with the provisional site class figures.

Height/Site class	Height class (m) Lackhan (1972)	Provisional site class** (m)
I	25.9	26.4
II	22.9	23.4
III	19.8	20.4

* Site index reference age for both classes is 20 years.

** Figures were from Table 6.5(a).

Among the most important factors determining the site quality of P. caribaea, and hence its growth rate, are the rainfall and soil depth. Various studies have shown that the soil depth generally limits the rooting zone of the species (Lamb, 1973). The 'c' parameter was more correlated with the total rainfall, RF, than the soil depth, SD, (Table 6.2.3(c)). Furthermore, the number of rainy days (per year), which gives an indication of rainfall distribution, is more important for tree growth than the total rainfall. Hence the 'c' parameter was more correlated with the number of rainy days than the total rainfall. Lamb (loc. cit.) has emphasised the impact of rainfall and soil depth on the growth of P. caribaea in many countries. He cited a total volume production of 644 m³/ha (volume underbark to 7.5 cm diameter top) at the age of 29 years in Zululand with an annual rainfall of about 1200 mm and a good rooting depth as compared with 582 m³/ha for the same age in Trinidad where these site characteristics were less favourable.

CHAPTER 7

CONCLUSIONS AND SUGGESTIONS

7.1. The Weibull diameter models

The Weibull distribution was found capable of accurately describing the diameter distribution as from the minimum age of 4 years in the E. cloeziana stands, 6 years in the E. tereticornis stands and as from the age of 5.7 years in the P. caribaea stands as already discussed in Section 6.1.1.

However, while the Weibull parameters could accurately be predicted from the stand attributes for E. cloeziana and E. tereticornis as from the minimum ages stated above, the Weibull parameters for P. caribaea could not be accurately predicted from the stand attributes (and site factors) until the attainment of minimum age of 10 years. From the explanations earlier given in Section 6.2.4.3, it follows that the Weibull distribution was acting

as a growth function as earlier noted by Yang et al (1978). In other words, the Weibull parameters could not be accurately predicted from the stand attributes until a reasonable amount of the site growth potentials must have been utilized. P. caribaea has a lower growth rate than the other two species and will therefore exploit the site growth potentials at a lower rate.

With given stand attributes, the constructed Weibull parameter models can be used to estimate diameter distribution in the stands of the species as from the minimum age limit stated for each species. The correlations of the Weibull parameters with age were somehow low because most of the stands were relatively young. It is however expected that, as the plantations grow older, the Weibull parameters would be accurately predicted from age and other easily measured variables like number of stems per hectare, minimum diameter, maximum diameter etc to facilitate projection of diameter distribution in the stands of the species.

In advanced forest management, a forester may decide on the trees to be thinned using the percentile method, e.g. 30 percentile of the trees to be removed without specifying the minimum diameter to remain in the stand after thinning. However, if the Weibull parameters have been obtained for such a stand, the minimum diameter to remain after thinning can be worked out using Model (26). Similarly, percentile of basal area to be removed may be used instead of percentile of the trees to be removed. Usually, some tree species are capable of retaining a certain maximum basal area at given site. Hence there is the need to keep the basal area constant as this maximum is reached otherwise mortality will occur leading to a loss for the forest owner. If the basal area of standing trees and the percentile of the basal area to be removed are known and the Weibull parameters have been obtained for such a stand, then the minimum diameter to remain in the stand after thinning can be obtained using Model (28). Once this minimum diameter is known, thinning operation goes faster.

The Weibull parameter predictive models constructed for the three species (i.e. E. cloeziana, E. tereticornis and P. caribaea) have been tested in both experimental and new stands and found suitable for application, though with some limitations regarding the minimum age limits as from which the models could give reliable predictions. The parameter predictive models for E. cloeziana are relatively simple while those for E. tereticornis and P. caribaea are somehow complex. It is likely that, when more data are available from old stands, less complex Weibull parameter models could be developed for these species. It is also hoped that, at that time, the relatively simple and less expensive DAGOS subroutine could be used for the determination of the parameters instead of the expensive subroutine based on the maximum likelihood method.

7.2 The volume models and growth and yield data

The tables for inter-correlations of the stand variables for the three species open a new avenue for further growth studies of the species. These have given indications of the stand variables that can be predicted from the easily measured ones.

The stand volume models are of commercial importance. Using these models, a forest owner can estimate the standing volumes of the species at any given time and convert these into money value. For the three species, the models predict standing volumes irrespective of site classification. This makes each model generally applicable, especially within the areas covered by the study. A further application of the constructed models will be for the production of stand volume tables for the species.

The average provisional site index curve has been defined as top height of 27.4 m at a reference age of 13 years for E. cloeziana, 24.8 m at age 15 for E. tereticornis and 23.4 m at age 20 for P. caribaea. Moreover, three provisional site index classes were demarcated for P. caribaea, viz: site class I (26.4 m at age 20), II (23.4 m at age 20), and III (20.4 m at age 20). These results will provide the basis for preliminary site classification of plantations of the species at the various locations.

From the provisional average total volume production-age curve constructed for each species,

the M.A.I is anticipated to culminate with a total volume production of about $240 \text{ m}^3/\text{ha}$ at age 13.4 years, $286 \text{ m}^3/\text{ha}$ at age 19.4 and $726 \text{ m}^3/\text{ha}$ at age 30.3 years for E. cloeziana, E. tereticornis and P. caribaea, respectively, on an average site. Based on these figures and on the assumption that the species will be utilized for sawnwood, a tentative rotation age of 19, 23 and 32 years has been fixed for E. cloeziana, E. tereticornis and P. caribaea respectively. So far, all these figures have provided tentative growth and yield figures for the species. It is however hoped that these will be improved upon as more data are available especially from older plantations.

On the whole, it is believed that the constructed Weibull parameter models for diameter distribution, the stand volume models, along with the provisional average site index curves and the total volume production-age curves will assist the wood-using industries in the country and the various forestry services, particularly the Kaduna State Forestry Division, in planning the uses and management of their resources.

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A P P E N D I C E S

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LIST OF APPENDICES

Appendix	Page
1a	Data input format for the original multi-Weibull programs
1b	Results from the original multi-Weibull programs
2a	Data input format for the modified multi-Weibull programs
2b	Results from the modified multi-Weibull programs with the sub-program, TEST, incorporated into some of the subroutines
3(a-h)	Listings of some of the data input programs
4(a-d)	Comparisons of the results from the different subroutines of the multi-Weibull programs with 'a' = 0.0 and 'a' = 0.999 x MnD (based on data of <u>E. tereticornis</u> at Kabama at ages 6.3, 7.3, 9.25 and 12.5 years).

LIST OF APPENDICES (CONTD)

Appendix		Page
5	Kolmogorov-Smirnov (K - S) two-sample test	
6	Computer programs for estimating cumulative gamma distribution and plotting this and cumulative distributions from different sub- routines of the multi-Weibull programs on common axes	
7(a-c)	Weibull parameters, stand attributes and site factors for <u>E. cloeziana</u> , <u>E. tereticornis</u> and <u>P. caribaea</u>	
8(a-c)	Top height - age data for <u>E. cloeziana</u> , <u>E. tereticornis</u> and <u>P. caribaea</u>	
9(a-c)	Data for inter-correlations of stand variables and stand volume models for <u>E. cloeziana</u> , <u>E. tereticornis</u> and <u>P. caribaea</u> .	

LIST OF APPENDICES (CONTD)

Appendix	Page
10(a)	Durbin-Watson Statistic table
10(b)	A table of gamma functions
11(a-c)	Comparisons of the observed and predicted standing volumes for <u>E. cloeziana</u> , <u>E. tereticornis</u> and <u>P. caribaea</u>
12(a-c)	Comparisons of the actual and predicted cumulative diameter frequency distributions in new stands of <u>E. cloeziana</u> , <u>E. tereticornis</u> and <u>P. caribaea</u>

Appendix 1(a)

Data input format for the original multi-weibull programs used by Okojie (1981).

26 443

1 62	1 70	1 103	1 112	1 132	1 135	1 138	1 139	1 140	1 143
1 145	1 152	1 153	1 157	1 163	1 182	1 204	1 211	1 229	1 259
1 263	1 281	1 299	1 312	1 377	1 443				

402050

1 150	1 200	1 270	1 420	1 420	1 430	1 440	1 460	1 640	1 650
1 650	1 680	1 680	1 710	1 740	1 750	1 750	1 760	1 770	1 780
1 920	1 950	11000	11020	11020	11120	11130	11160	11170	11240
11240	11260	11270	11340	11490	11520	11530	11610	11680	12050

401851

1 409	1 522	1 532	1 594	1 600	1 668	1 773	1 780	1 797	1 811
1 814	1 854	1 860	1 863	1 874	1 885	1 899	1 924	1 930	1 932
11087	11093	11116	11131	11142	11177	11216	11219	11276	11280
11297	11308	11341	11375	11392	11403	11530	11538	11833	11851

APPENDIX 1(b)

Results from the original multi - weibull programs

UNBIASED VERSIONS OF WINWAR AND FITTER NEW SAMPLE SIZE = 26

FREQ	VALUE																
1	6.2	1	7.0	1	10.3	1	11.2	1	13.2	1	13.5	1	13.8	1	13.9	1	14.3
1	14.5	1	15.2	1	15.3	1	15.7	1	16.3	1	18.2	1	20.4	1	21.1	1	25.9
1	26.3	1	28.1	1	29.9	1	31.2	1	37.7	1	44.3	0	0.0	0	0.0	0	0.0

WEIBULL PARAMETERS -----

	A	B	C	AMAX
DAGOSTINO	0.00000000	21.56989862	2.23212854	6.19900000
WINGO	5.55252754	14.95965904	1.44973899	
WINGO	5.55252754	15.18076743	1.53087538	
FITTER	5.55252754	14.95965885	1.44973892	WINWAR ESTIMATE FOR A-PARAMETER
FITTER	5.00000000	15.70820479	1.54284207	A-PARAMETER TO NEAREST 1.0
FITTER 2	5.55252754	15.18076723	1.53087531	
FITTER 2	5.00000000	15.93430763	1.62918909	
HARTER	5.55251761	15.18078833	1.53087801	NO CORRECTION FOR BIAS

UNBIASED VERSIONS OF WINWAR AND FITTER NEW SAMPLE SIZE = 40

FREQ	VALUE																		
1	15.0	1	20.0	1	27.0	1	42.0	1	42.0	1	43.0	1	44.0	1	46.0	1	64.0	1	65.0
1	65.0	1	68.0	1	68.0	1	71.0	1	74.0	1	75.0	1	75.0	1	76.0	1	77.0	1	78.0
1	92.0	1	95.0	1	100.0	1	102.0	1	102.0	1	112.0	1	113.0	1	116.0	1	117.0	1	124.0
1	124.0	1	126.0	1	127.0	1	134.0	1	149.0	1	152.0	1	153.0	1	161.0	1	168.0	1	205.0

WEIBULL PARAMETERS -----

	A	B	C	AMAX
DAGOSTINO	0.00000000	104.08612072	2.229826414	14.99900000
WINGO	2.47945135	101.14455225	2.12462281	
WINGO	2.47945135	101.79398735	2.19940249	
FITTER	2.47945135	101.14452810	2.12462005	WINWAR ESTIMATE FOR A-PARAMETER
FITTER	2.00000000	101.69695918	2.13883289	A-PARAMETER TO NEAREST 1.0
FITTER 2	2.47945135	101.79396267	2.19939963	
FITTER 2	2.00000000	102.34706418	2.21411272	
HARTER	2.47859209	101.79496812	2.19942659	NO CORRECTION FOR BIAS

Data input format for the modified multi-Weibull programs.

78 78

110.2	110.5	110.8	110.8	110.8	111.1	111.1	111.8	111.8	111.8
112.1	112.1	112.1	112.4	112.4	112.7	112.7	113.0	113.0	113.0
113.4	113.4	113.4	113.7	113.7	113.7	113.7	113.7	114.0	114.0
114.0	114.0	114.0	114.0	114.0	114.0	114.3	114.3	114.3	114.3
114.3	114.6	114.6	114.6	114.6	114.6	114.6	114.6	114.6	114.6
114.9	114.9	114.9	115.2	115.2	115.6	115.6	115.6	115.6	115.9
115.9	116.2	116.2	116.2	116.5	116.5	116.5	116.8	116.8	117.5
117.5	117.5	117.8	118.4	118.4	118.4	119.1	119.7	0 0.0	0 0.0

78 78

110.5	110.8	111.1	111.1	111.1	111.4	111.8	112.4	112.4	112.4
112.7	113.0	113.4	113.4	113.7	113.7	114.0	114.0	114.0	114.0
114.0	114.0	114.3	114.3	114.3	114.3	114.6	114.6	114.6	114.6
114.6	114.6	114.6	114.9	114.9	114.9	114.9	115.2	115.2	115.2
115.2	115.2	115.2	115.2	115.6	115.9	115.9	116.2	116.2	116.2
116.2	116.2	116.2	116.2	116.2	116.2	116.5	116.5	116.8	116.8
117.2	117.2	117.5	117.5	117.5	117.5	117.8	117.8	118.1	118.4
118.8	118.8	119.1	119.1	119.1	119.1	120.0	122.6	0 0.0	0 0.0

46 46

114.9	115.6	115.9	116.5	116.8	116.8	116.8	116.8	116.8	117.2
117.2	117.2	117.2	117.5	117.8	117.8	117.8	118.1	118.1	118.1
118.1	118.4	118.4	118.8	118.8	118.8	118.8	118.8	119.1	119.7
119.7	119.7	120.0	120.0	120.4	120.7	120.9	121.0	121.0	121.0
121.3	121.3	122.3	122.3	123.2	128.3	0 0.0	0 0.0	0 0.0	0 0.0

46 46

117.5	117.8	118.1	118.4	118.8	118.8	119.1	119.1	119.1	119.1
119.7	119.7	119.7	120.0	120.0	120.4	120.4	120.7	120.7	120.7
121.0	121.0	121.3	121.3	121.6	121.6	121.6	121.9	121.9	121.9
122.3	122.6	122.6	123.2	123.5	123.8	123.8	124.5	124.5	124.5
124.8	125.4	126.1	126.4	129.7	134.0	0 0.0	0 0.0	0 0.0	0 0.0

APPENDIX 2(b)

Results from the modified multi-weibull programs with the sub-program, TEST, incorporated into some of the subroutines giving diameter distribution per plot directly.

(a) Number of trees/plot = 28

HSPA = 28

UNBIASED VERSIONS OF WINWAR AND FITTER NEW SAMPLE SIZE = 28

FREQ	VALUE	FREQ	VALUE	FREQ	VAL	RPEQ	VAL	FREQ	VAL	FREQ	VAL								
1	4.1	1	5.1	1	5.4	1	5.4	1	5.7	1	6.0	1	6.0	1	6.7	1	7.0	1	7.0
1	7.0	1	7.3	1	7.3	1	7.6	1	8.0	1	8.3	1	8.6	1	8.6	1	8.9	1	9.5
1	9.5	1	10.3	1	10.8	1	10.8	1	11.1	1	12.7	1	12.7	1	14.6	0	0.0	0	0.0

DAGOSTINO

WEIBULL PARAMETERS:

A = 4.09900000 B = 4.36719447 C = 1.37158801 AMAX = 4.09900000

TOTAL = 28

DISTRIBUTION: 0 3 10 7 4 2 1 1 0 0 0 0 0 0 0 0 0 0 0 0

CLASS WIDTH = 2.00

MODE = 5.78436895 MEAN = 8.09267184 QUADRATIC MEAN = 8.61227498 VARIANCE = 8.67994276

PERCENTILES:

P(I) = 0.05000000 0.95000000

X(P(I)) = 4.59987695 13.81779105

GAMMA-ONE = 0.91447080 GAMMA-TWO = 1.2913621

WINGO

WEIBULL PARAMETERS:

A = 3.73556007 B = 5.12174075 C = 1.86566651 AMAX = 4.09900000

TOTAL = 28

DISTRIBUTION: 0 2 8 8 6 3 1 0 0 0 0 0 0 0 0 0 0 0 0 0

CLASS WIDTH = 2.00

MODE = 7.12923312 MEAN = 8.28327676 QUADRATIC MEAN = 8.66132728 VARIANCE = 6.40591645

PERCENTILES:

P(I) = 0.05000000 0.95000000

X(P(I)) = 4.77789711 12.95753423

GAMMA-ONE = 0.88792403 GAMMA-TWO = 1.0326093

APPENDICES 3(a - h)

SOME OF THE DATA INPUT PROGRAMS

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APPENDIX 3(a)

```

VTREES[ ]V
VTREES:C;X;V;P;J;Y;M;FN;FN1;A;AGES;YS;NO;K;E;SE;SK;MAX;MIN;RES
[1]  A VERSION OF 8/2/83.
[2]  'ENTRY OF TREES FROM TERMINAL.'
[3]  L00:'ENTER ONE OF THE FOLLOWING:'
[4]  '1 TO START FROM SCRATCH,'
[5]  '2 TO RESUME ENTERING DATA,'
[6]  '3 TO GET STATISTICS FROM EXISTING FILE,'
[7]  '4 TO WRITE COMPUTING FILE IMMEDIATELY.'
[8]  +(~V/1 2 3 4eC+[])/L00
[9]  L01:+(C1,C2,C3,C2)[C]
[10] C1:'NAME YOUR FILE.' A SCRATCH
[11] FN1+'X'.6+FN+[]
[12] FN1 FCREATE F+1+[ /O,FNUMS
[13] FUNTIE F
[14] C10:'ENTER AGES.'
[15] N+pAGES+[]
[16] 'N OF OBS:'.10 2*N
[17] 'AREA IN SQ. METRES =?'
[18] A+[]
[19] 'START ENTERING DATA.'
[20] 'LEAVE AT LEAST ONE SPACE BETWEEN ANY TWO NUMBERS.'
[21] 'IF YOU MAKE A TYPING MISTAKE, PRESS LINE FEED.'
[22] 'THEN BACKSPACE TO THE POINT OF CORRECTION.'
[23] 'WHEN YOU HAVE FINISHED, RETURN AGAIN WITHOUT'
[24] 'TYPING ANYTHING.'
[25] X+1I+0
[26] L0:+(0=pV+[])/STOP A DATA ENTERING LOOP
[27] +(N=-1+pV+±V)/L1
[28] 'TOO MANY OR TOO FEW NUMBERS. TRY AGAIN.'
[29] +L0
[30] L1:+(V[1]=I+1)/L2
[31] 'WRONG SERIAL NUMBER. TRY AGAIN.'
[32] +L0
[33] L2:I+I+1
[34] X+X,1+V
[35] +L0
[36] L20:CORRECT
[37] +0
[38] STOP:'HALT, FINISH OR CORRECT?'
[39] +('F'=1+,RES+[])/END
[40] +('C'=1+RES)/L20
[41] 'HALTED. SEE YOU LATER.'
[42] RECORD
[43] +0
[44] END:(FN,'/C')FCREATE F+1+[ /O,FNUMS
[45] L21:X+0(I,N)pX
[46] YS-NO+K-E+SE-SK+MAX+MIN+1I+0
[47] L3:+(N<I+I+1)/FIN A COMPUTE STATISTICS.
[48] M+pY-(Y≠0)/Y+X[I;]
[49] Y+Y[ΔY]
[50] E+E,EI+MEAN Y
[51] SE+SE,SD Y
[52] SK+SK,MEAN(Y-EI)*3
[53] MAX+MAX,[ /Y
[54] MIN+MIN,[ /Y
[55] NO+NO,pY
[56] K+K,MEAN(Y-EI)*4
[57] YS+YS,+ /Y*2
[58] +(3=C)/L22 A SKIP THE WRITE OF M
[59] (4 0 6 1*M,M)CFWRITE F
[60] L22:Y+((2*M)p0 1)\Y
[61] Y+Y+(2*M)p1 0

```

APPENDIX 3(a) (CONTD)

```

[62] M+M+10
[63] +(3=C)/L3 R STATISTICS
[64] J+0
[65] L30:+(M<J+J+1)/L3
[66] ((40p4 0 4 1)∇20+Y)CFWRITE F
[67] Y+20+Y
[68] →L30
[69] FIN:'FINISHED.'
[70] 'AGES: ',10 2∇AGES
[71] 'MEANS: ',10 2∇E
[72] 'S.D.'S: ',10 2∇SE
[73] 'SKEWNESS: ',10 2∇SK+SE*3
[74] 'MAXIMA: ',10 2∇MAX
[75] 'MINIMA: ',10 2∇MIN
[76] 'KURTOSIS: ',10 2∇K+SE*4
[77] 'SE OF MEAN: ',10 2∇SE+NO*0.5
[78] 'NO. OF OBS: ',10 0∇NO
[79] 'M. CROP/HA: ',10 2∇10000×NO+A
[80] 'B.A.M.CROP/HA: ',10 2∇((0.25×01)×YS)+A
[81] +(3≤C)/L4
[82] X←10
[83] 'MORE PLOTS?'
[84] +('Y'=1+,□)/C10
[85] FUNTIE FNUMS
[86] +0
[87] C2:'NAME OF RANDOM-ACCESS FILE, PLEASE.' R RESUME OR COPY.
[88] FN+1+FN1+□
[89] RESTORE
[90] +(4=C)/END R COPY (TO OKOJIE'S FILE.)
[91] 'CURRENT LINE NUMBER = ':I+1
[92] 'FORWARD!'
[93] →L0
[94] C3:'STATISTICS ONLY, FROM FILE.'
[95] 'FILE NAME?'
[96] FN1+□
[97] RESTORE
[98] I+[(pX)+N+pAGES
[99] →L21
[100] L4:FUNTIE FNUMS
∇

```

APPENDIX 3(a) (CONTD)

```

VMEAN[ ]V
VM+MEAN X
[1] M+(+/X)^-1+pX
V

VSD[ ]V
VS+SD X
[1] S+(MEAN(X-MEAN X)*2)*0.5
V

VRECORD[ ]V
VRECORD;F2;N;M;J
[1] FN1 FTIE F2+1+[ /0,FNUMS
[2] AGES FWRITE F2
[3] N+pAGES
[4] M+(pX)+N
[5] A FWRITE F2
[6] I FWRITE F2
[7] J+0
[8] LO:-(M<J+J+1)/L1
[9] (N+X)FWRITE F2
[10] X+N+X
[11] +LO
[12] L1:FUNTIE F2
V

VRESTORE[ ]V
VRESTORE;F2;J
[1] FN1 FTIE F2+1+[ /0,FNUMS
[2] +((FSTATUS F2)[7])/L2
[3] N+pAGES+FREAD F2
[4] A+FREAD F2
[5] I+FREAD F2
[6] X+iJ+0
[7] LO:-(I<J+J+1)/L1
[8] X+X,FREAD F2
[9] +LO
[10] X+FREAD F2
[11] L1:FERASE F2
[12] +0
[13] L2:N+pAGES+eCFREAD F2
[14] A+eCFREAD F2
[15] I+eCFREAD F2
[16] X+iJ+0
[17] L3:-(I<J+J+1)/L1
[18] X+X,eCFREAD F2
[19] +L3
V

```

APPENDIX 3(b)

```

VWRITER[ ]V
VWRITER Z;F
[1]  A WRITE AN OKOJIE-STYLE FILE.
[2]  'SPECIFY OUTPUT FILE.'
[3]  ( [ ] , '/' C ' ) PCREATE P+1+[ / 0 , PNUMS
[4]  N+pZ
[5]  M+[ N+20
[6]  I+0
[7]  ( 4 0 5 0 * N , N ) CPWRITE P
[8]  LO:-( M < I + I + 1 ) / L1
[9]  ( ( 4 0 p 4 0 4 1 ) * 20 + Z ) CPWRITE P
[10] Z+20+Z
[11] →LO
[12] L1: 'FINISHED. ' ; M ; ' RECORDS WRITTEN. '
[13] PUNTIE P
V

```

```

VWRITER1[ ]V
VWRITER1 Z;F
[1]  A WRITE AN OKOJIE-STYLE FILE.
[2]  A SUPPLIES 'FREQUENCIES' OF 1.
[3]  'SPECIFY OUTPUT FILE.'
[4]  ( [ ] , '/' C ' ) PCREATE P+1+[ / 0 , PNUMS
[5]  N+pZ
[6]  M+[ N+20
[7]  I+0
[8]  ( 4 0 5 0 * N , N ) CPWRITE P
[9]  LO:-( M < I + I + 1 ) / L1
[10] X←, [ 1 , [ 0 . 5 ] 10 + Z
[11] ( ( 4 0 p 4 0 4 1 ) * X ) CPWRITE P
[12] Z+10+Z
[13] →LO
[14] L1: 'FINISHED. ' ; M ; ' RECORDS WRITTEN. '
[15] PUNTIE P
V

```

```

VWORK[ ]V
VWORK
V
[ ] EX 'WORK'

```

1

```

) VARS
F LO N RC TESSY TITLE X

```

pX

20

pRC

2 14

APPENDIX 3(c)

```

VCOMBINE[ ]V
VCOMBINE:F1;VN;X;V
[1] 'COMBINE WORKING FILES.'
[2] U+'NAME FOR COMBINED FILE? '
[3] (U, '/C')FCREATE F2+1+[ /O, FNUMS
[4] 'ENTER NAMES OF EXISTING FILES, SEPARATED BY SPACES.'
[5] V+MATRIFY VN+U
[6] F1+F2+1
[7] N+1+pV
[8] I+0
[9] L0:+(N<I+1)/L3
[10] V[I;]FTIE F1
[11] V[I;]CFWRITE F2
[12] L1:+(O=ppX+CFREAD F1)/L2
[13] X CFWRITE F2
[14] +L1
[15] L2:FUNTIE F1
[16] 'DHOP ',V[I;].'? '
[17] +('Y'≠1+,U)/L0
[18] [ ]DHOP V[I;]
[19] +L0
[20] L3:'FINISHED.'
[21] FUNTIE FNUMS
V

```

```

VMATRIFY[ ]V
VZ+MATRIFY V;I;P;L;B
[1] ' CONVERTS A VECTOR OF NAMES TO A MATRIX OF NAMES.
[2] I+' 'xV+V.' '
[3] B=I/IΛ-1OI
[4] V+I/V
[5] B+B/1pB
[6] P=[ /O, L+((1+B), 1+pV)-B
[7] Z-((pB), P)p(, L°.z, P)\V
V

```

APPENDIX 3(d)

```

VREADER[ ]V
VZ←READER;P;V;M
[1]  R READ A FILE SUCH AS COMB4. COUNT.
[2]  'FILE NAMES?'
[3]  [ ] FTIE F←1+[ /0,FNUMS
[4]  Z←1M←0
[5]  L0:→(0=ppV+CFREAD P)/L1
[6]  Z←Z,V←(V≠0)/V←±V
[7]  M←M[L /V
[8]  →L0
[9]  L1:'FINISHED.'
[10] 'ACTUAL COUNT: ';pZ
[11] 'MINIMUM = ';M
[12] FUNTIE F
V

VSRT1[ ]V
VZ←SRT1 X
[1]  R SORT THE DATA AND PRODUCE PAIRS (1,OBSERVATION).
[2]  Z←,Q1,[0.5]Z+X[AX]
V

VSRTFREQ0[ ]V
VZ←SRTFREQ0 X;F
[1]  R SORT X AND OBTAIN FREQUENCIES.
[2]  X←X[AX]
[3]  F←+/X←X
[4]  Z←((X+X)=1pX)/X
[5]  Z←,QF,[0.5]Z
V

VSRTFREQ[ ]V
VZ←SRTFREQ X;M;I;J
[1]  R SORT X AND OBTAIN FREQUENCIES. VERSION FOR LONG X.
[2]  M←2+pX←X[AX]
[3]  Z←1I←J←0
[4]  L0:→(M<I+I+1)/L1
[5]  J←J+1
[6]  →(X[I]=X[I+1])/L0
[7]  Z←Z,J,X[I]
[8]  J←0
[9]  →L0
[10] L1:Z←Z,J,X[I+1]
V

```

APPENDIX 3(e)

```

▽ADDAGES[□]▽
▽ADDAGES;F;I;N;M;AGES
[1]  A ADD MORE AGES TO RANDOM ACCESS FILE.
[2]  'FILE NAME?'
[3]  □ FTIE F←1+[ /O,FNUMS
[4]  N←ρAGES←FREAD F
[5]  I←2
[6]  'WE HAVE ';N;' AGES: ';AGES
[7]  'THE AUGMENTED LIST OF AGES?'
[8]  N←ρAGES←□
[9]  AGES FWRITE F,0
[10] M←FREAD F,2
[11] L0:→(M<I+I+1)/L1
[12] □+(▽X←FREAD F,I),''
[13] L01:X←X,±□
[14] →(N=ρX)/L2
[15] 'TOO FEW OR TOO MANY NUMBERS. TRY AGAIN.'
[16] →L01
[17] L2:X FWRITE F,I
[18] →L0
[19] L1:'FINISHED.'
[20] FUNTIE F
▽

```

```

▽NAMELIST[□]▽
▽NAMELIST;F1;V
[1]  A LIST THE NAMES IN A COMBINED FILE.'
[2]  'NAME OF THE FILE, PLEASE.'
[3]  ALF←'ABCDEFGHIJKLMNPOQRSTUVWXYZ'
[4]  □ FTIE F1←1+[ /O,FNUMS
[5]  L0:→(0=ρρV←CFREAD F1)/END
[6]  →(∼V/ALFεV)/L0
[7]  □+V
[8]  →L0
[9]  END:'FINISHED.'
[10] FUNTIE F1
▽

```

APPENDIX 3(f)

```

VCORRECT[U]V
VCORRECT;F;N;X;I
[1] 'CORRECT THE RANDOM-ACCESS FILE.'
[2] FN1 FTIE F+1+[I/O,FNUMS
[3] LO:'SERIAL NUMBER OF RECORD TO BE CORRECTED, PLEASE.'
[4] I+U
[5] N+pFREAD F
[6] M+FREAD F,2
[7] FREAD F,2+I
[8] 'THE ONE YOU WANT?'
[9] +('N'=1+,U)/LO
[10] 'ENTER THE CORRECT RECORD.'
[11] X+1+U
[12] X FWRITE F,2+I
[13] 'ANY MORE?'
[14] +('Y'=1+,U)/LO
[15] PUNTIE F
V

VCOPIRC[U]V
VCOPIRC;FN;F1;F2;N;I
[1] A COPY, LITERALLY, RANDOM ACCESS FILE TO CODED FILE.
[2] U+'NAME OF RANDOM ACCESS FILE? '
[3] FN+(FN+' ')/FN+U
[4] FN FTIE F1+1+[I/O,FNUMS
[5] (('C',1+FN),'/C')FCREATE F2+1+F1
[6] (VFREAD F1)CFWRITE F2
[7] (VFREAD F1)CFWRITE F2
[8] (VN+FREAD F1)CFWRITE F2
[9] I+0
[10] LO:+(N<I+1)/L1
[11] (VFREAD F1)CFWRITE F2
[12] +LO
[13] L1:I;' OBSERVATIONS COPIED.'
[14] FUNTIE FNUMS
[15] U+'DROP RANDOM ACCESS FILE? '
[16] +('N'=1+,U)/O
[17] UDROP FN
V

VSEEDATA[U]V
VSEEDATA;F;X;FN1;J
[1] A SEE THE DATA IN RANDOM ACCESS FILE.
[2] 'NAME OF RANDOM ACCESS FILE?'
[3] (FN1+U)FTIE F+1+[I/O,FNUMS
[4] N+pFREAD F,0
[5] I+FREAD F,2
[6] J+0
[7] LO:+(I<J+J+1)/L1
[8] (4 0+J),8 2VFREAD F
[9] +LO
[10] L1:FUNTIE F
[11] 'WANT TO CORRECT IT?'
[12] +('N'=1+,U)/O
[13] CORRECT
V

```

APPENDIX 3(g)

```

VSPLO
  ITOFF[ ]V
VSPLOFF FN;F1;F2;N;I
[1]  A SPLIT OFF SECTIONS OF A RANDOM ACCESS FILE
[2]  A ONTO SMALLER FILES.
[3]  FN FTIE F1+1+[ /O,FNUMS
[4]  FPOS F1,3
[5]  LO:'NAME THE NEW FILE.'
[6]  [ ] FCREATE F2+1+F1
[7]  'ENTER AGES.'
[8]  [ ] FWRITE F2
[9]  'ENTER AREA.'
[10] [ ] FWRITE F2
[11] FPOS F2,3
[12] 'HOW MANY RECORDS?'
[13] N+[ ]
[14] I+0
[15] L1:-(N<I+I+1)/L2
[16] (FREAD F1)FWRITE F2
[17] +L1
[18] L2:I FWRITE F2,2
[19] FUNTIE F2
[20] 'MORE?'
[21] +('Y'=1+[ ])/LO
[22] 'FINISHED.'
[23] FUNTIE F1
V

VEXTRACT[ ]V
VEXTRACT;F1;F2;FN;V;I;J;ALF
[1]  A EXTRACT A SUBFILE FROM A COMBINED FILE.
[2]  'NAME OF THE BIG FILE?'
[3]  [ ] FTIE F1+1+[ /O,FNUMS
[4]  'NAME OF THE SUBFILE?'
[5]  FN+(FNz' ')/FN+[ ]
[6]  ALF+'ABCDEFGHIJKLMNOPQRSTUVWXYZ'
[7]  I+J+0
[8]  LO:+(0=ppV+CFREAD F1)/FAIL
[9]  J+J+1
[10] +(~^/FNεV+(Vz' ')/V)/LO
[11] V
[12] (FN,'/C')FCREATE F2+1+F1
[13] L1:-(V/ALFεV)∨0=ppV+CFREAD F1)/END
[14] I+I+1
[15] V CFWRITE F2
[16] +L1
[17] FAIL:'NO SUCH SUBFILE!'
[18] END:'FINISHED. ';J;' RECORDS READ. ';I;' RECORDS COPIED.'
[19] FUNTIE FNUMS
V

```

APPENDIX 3(h)

```

VDELETER[ ]V
VDELETER;F1;F2;V;I;DR;DC
[1] 'DELETE ROWS AND COLUMNS.'
[2] 'WHAT ROWS? (IF NONE, SAY ''NONE.'')'
[3] DR←, [ ]
[4] 'WHAT COLUMNS? (IF NONE, SAY ''NONE.'')'
[5] DC←, [ ]
[6] [ ]←'FROM WHAT FILE? '
[7] [ ] FITE F1←1+[ /0, FNUMS
[8] 'TOO/C' FCREATE F2←1+F1
[9] I←0
[10] L0:→(0=ppV←CREAD F1)/L2
[11] I←I+1
[12] →(~I∈DR)/L1
[13] 'RECORD ';I;': ',V
[14] 'DELETE IT?'
[15] →('Y'=1↑,[ ])/L0
[16] L1:V←(~(1pV)∈DC)/V+qV
[17] (vV)CFWRITE F2.
[18] →L0
[19] L2:0 CFPOS F1
[20] 0 CFPOS F2
[21] L3:→(0=ppV←CFREAD F2)/END
[22] V CFWRITE F1
[23] →L3
[24] END:PERASE F2
[25] FUNTIE F1
[26] 'FINISHED.'
V

```

APPENDICES 4(a - d)

COMPARISONS OF THE RESULTS FROM
THE DIFFERENT SUBROUTINES OF THE MULTI-
WEIBULL PROGRAMS WITH 'a' PARAMETER = 0.0
AND 'a' = 0.999 x MnD USING DATA
OF E. TERETICORNIS AT KABAMA AT
AGES 6.3, 7.3, 9.25 AND 12.5 YRS.

APPENDIX 4(a)

E. TERETICORNIS, KABAMA, SAMPLE SIZE = 77, AGE = 6.3 YRS

X(P(I))
PERCENTILE P(I)=

a = 0.00

	a	b	c	MAX*	MODE	MD	Dq	VARIANCE	GAMMA**	GAMMA2	0.0500	0.9500
DAGOSTINO	0.0000	15.3274	7.2184	10.1990	15.0140	18.3606	14.5508	5.4990	0.9369	0.9012	10.1570	17.9435
WINGO	9.2690	5.7901	2.5964	"	14.0700	14.4116	14.5677	4.5252	0.8882	0.9238	11.1135	18.1040
WINGO	9.2690	5.8056	2.6413	"	14.1177	14.4281	14.5804	4.4166	0.8886	0.9207	11.1547	18.0643
FITTER 1	9.2690	5.7901	2.5964	"	14.0700	14.4116	14.5677	4.5252	0.8882	0.9238	11.1135	18.1040
FITTER 1.0	9.0000	6.0835	2.7479	"	14.1600	14.4133	14.5696	4.5300	0.8898	0.9142	11.0641	18.0690
FITTER 2	9.2690	5.8056	2.6413	"	14.1177	14.4281	14.5804	4.4166	0.8886	0.9207	11.1547	18.0643
FITTER 2.0	9.0000	6.0992	2.7954	"	14.2058	14.4307	14.5831	4.4213	0.8904	0.9117	11.1078	18.0508
HARTER	9.2687	5.8059	2.6415	"	14.1178	14.4281	14.5804	4.4166	0.8886	0.9207	11.1547	18.0643

SAMPLE SIZE = 77, AGE = 6.3 YRS, 'a' = 0.999 x Mnd

DAGOSTINO	10.1990	4.6252	1.8642	10.1990	13.2612	14.2059	14.4876	5.2315	0.8879	1.0330	11.1391	18.5305
WINGO	9.2689	5.7902	2.5965	"	14.0700	14.4116	14.5677	4.5252	0.8882	0.9238	11.1134	18.1040
WINGO	9.2689	5.8057	2.6414	"	14.1177	14.4281	14.5804	4.4166	0.8886	0.9207	11.1547	18.0643
FITTER 1	9.2689	5.7902	2.5965	"	14.0700	14.4116	14.5677	4.5252	0.8882	0.9238	11.1134	18.1040
FITTER 1.0	9.0000	6.0835	2.7479	"	14.1600	14.4133	14.5696	4.5300	0.8898	0.9142	11.0641	18.0690
FITTER 2	9.2689	5.8057	2.6414	"	14.1177	14.4281	14.5804	4.4166	0.8886	0.9207	11.1547	18.0643
FITTER 2.0	9.0000	6.0992	2.7954	"	14.2058	14.4307	14.5831	4.4213	0.8904	0.9117	11.1078	18.0508
HARTER	9.2690	5.8056	2.6413	"	14.1176	14.4281	14.5804	4.4166	0.8886	0.9207	11.1547	18.0643

* Refers to maximum value of 'a' parameter.

** $GAMMA = (MD - a)/b$

$GAMMA2 = (VARIANCE/b^2) + GAMMA^2$

MD = Arithmetic mean diameter

Dq = Quadratic mean diameter.

APPENDIX 4(b)

E. TERETICORNIS, KABAMA, SAMPLE SIZE = 77, AGE = 7.3 YRS.

a = 0.00

X(P(I))
PERCENTILE P(I) =

	a	b	s	AMAX	MODE	MD	Dq	VARIANCE	GAMMA1	GAMMA2	0.0500	0.9500
DAGOSTINO	0.0000	16.3463	6.8294	10.4990	15.9717	15.2712	15.4953	6.8924	0.9342	0.8986	10.5813	19.1952
WINGO	9.2411	6.8424	2.7750	"	15.0658	15.3319	15.5146	5.6352	0.8902	0.9127	11.5872	19.4018
WINGO	9.2411	6.8599	2.8229	"	15.1164	15.3513	15.5294	5.4998	0.8907	0.9103	11.6364	19.3594
FITTER 1	9.2411	6.8424	2.7750	"	15.0658	15.3319	15.5146	5.6352	0.8902	0.9127	11.5872	19.4018
FITTER 1.0	9.0000	7.1024	2.8932	"	15.1340	15.3325	15.5158	5.6526	0.8916	0.9070	11.5442	19.3778
FITTER 2	9.2411	6.8599	2.8229	"	15.1164	15.3513	15.5294	5.4998	0.8907	0.9103	11.6364	19.3594
FITTER 2.0	9.0000	7.1200	2.9432	"	15.1833	15.3527	15.5314	5.5166	0.8922	0.9049	11.5954	19.3366
HARTER	9.2409	6.8600	2.8230	"	15.1165	15.3514	15.5294	5.4998	0.8907	0.9103	11.6364	19.3594

SAMPLE SIZE = 77, AGE = 7.3 YRS., 'a' = 0.999 x MnD

DAGOSTINO	10.4990	5.2995	1.8936	10.4990	14.0536	15.2020	15.4198	6.6693	0.8075	1.0251	11.6032	19.9584
WINGO	9.2412	6.8422	2.7749	"	15.0657	15.3319	15.5146	5.6352	0.8901	0.9127	11.5873	19.4019
WINGO	9.2412	6.8597	2.8229	"	15.1164	15.3513	15.5294	5.4998	0.8907	0.9103	11.6364	19.3595
FITTER 1	9.2412	6.8422	2.7749	"	15.0657	15.3319	15.5145	5.6352	0.8901	0.9127	11.5873	19.4018
FITTER 1.0	9.0000	7.1024	2.8932	"	15.1340	15.3325	15.5158	5.6526	0.8916	0.9070	11.5442	19.3778
FITTER 2	9.2412	6.8597	2.8228	"	15.1164	15.3516	15.5294	5.4998	0.8907	0.9103	11.6364	19.3595
FITTER 2.0	9.0000	7.1200	2.9432	"	15.1833	15.3527	15.5314	5.5166	0.8922	0.9049	11.5954	19.3366
HARTER	9.2412	6.8599	2.8229	"	15.1164	15.3513	15.5294	5.4998	0.8907	0.9103	11.6364	19.3595

APPENDIX 4(c)

E. TERETICORNIS, KABAMA, SAMPLE SIZE = 45, AGE = 9.25 YRS.

X(P(I))
PERCENTILE P(I)=

a = 0.00

	a	b	c	MAX	MODE	MD	Dq	VARIANCE	GAMMA1	GAMMA2	0.0500	0.9500
DA COSTINO	0.0000	19.9924	7.4978	14.8990	19.6143	18.7675	18.9992	8.7508	0.9387	0.9031	13.4531	23.1429
WINGO	14.9000	4.0785	0.9705	"	14.9000	19.0325	19.5031	18.1363	1.0132	2.1169	15.0911	27.5325
WINGO	14.9000	4.0978	1.0000	"	14.9000	18.9978	19.4347	16.7917	1.0000	2.0000	15.1102	27.1758
FITTER 1	14.9000	4.2822	1.2901	"	16.2469	18.8611	19.1153	9.5782	0.9250	1.3780	15.3283	24.9234
FITTER 1.0	14.0000	5.6103	2.1548	"	18.2136	18.9684	19.1221	5.8503	0.8860	0.9702	15.4227	23.3131
FITTER 2	14.9000	4.3066	1.3293	"	16.4075	18.8603	19.0987	9.0502	0.9196	1.3336	15.3611	24.7309
FITTER 2.0	14.0000	5.6462	2.2306	"	18.3248	19.0007	19.1480	5.6165	0.8857	0.9606	15.4910	23.2337
HARTER	14.6516	4.8945	1.9254	"	17.9969	18.9931	19.1377	5.5155	0.8870	1.0170	15.6981	23.3052

SAMPLE SIZE = 45, AGE = 9.25 YRS, 'a' = 0.999 x MnD

DA COSTINO	14.8990	4.4263	1.5762	14.8990	17.2366	18.8731	19.0484	6.6472	0.8978	1.1454	15.5714	23.7777
WINGO	14.6516	4.0607	1.8686	"	17.8774	18.9673	19.1183	5.7529	0.8879	1.0318	15.6432	23.3956
WINGO	14.6516	4.0945	1.9254	"	17.9969	18.9931	19.1377	5.5155	0.8870	1.0170	15.6991	23.3052
FITTER 1	14.6516	4.8607	1.8686	"	17.8774	18.9673	19.1183	5.7529	0.8879	1.0318	15.5432	23.3956
FITTER 1.0	14.0000	5.6103	2.1648	"	18.2136	18.9685	19.1221	5.8503	0.8856	0.9702	15.4227	23.3131
FITTER 2	14.6516	4.8945	1.9254	"	17.9969	18.9931	19.1377	5.5155	0.8870	1.0170	15.6981	23.3052
FITTER 2.0	14.0000	5.6462	2.2306	"	18.3248	19.0007	19.1480	5.6165	0.8857	0.9606	15.4910	23.2337
HARTER	14.6516	4.8945	1.9254	"	17.9969	18.9931	19.1377	5.5155	0.8870	1.0170	15.6981	23.3052

APPENDIX 4(d)

E. TERETICORNIS, KABAMA, SAMPLE SIZE = 45, AGE = 12.5 YRS.

$\alpha = 0.00$

	a	b	c	ANAX	MODE	MD	Dq	VARIANCE	C.MEAN1	X(P(I)) PERCENTILE P(I)=			
										0.0125	0.0500	0.9500	0.9500
DAGOSTINO	0.0000	23.1730	6.4592	17.4990	22.5792	21.5866	21.9344	15.2260	0.9315	0.8961	14.6414	27.4562	
WINDO	17.3819	4.9370	1.4385	"	19.5437	21.8634	22.0910	10.0034	0.9077	1.2344	18.0082	27.9675	
WINDO	17.3819	4.9797	1.4822	"	19.7165	21.8840	22.1011	9.5514	0.9041	1.2025	18.0532	27.8215	
FITTER 1	17.3819	4.9370	1.4385	"	19.5437	21.8634	22.0910	10.0034	0.9077	1.2344	18.0082	27.9675	
FITTER 1.0	17.0000	5.4415	1.6090	"	19.9750	21.8762	22.0953	9.6366	0.8961	1.1285	17.8591	27.7612	
FITTER 2	17.3819	4.9797	1.4822	"	19.7165	21.8840	22.1011	9.5514	0.9041	1.2025	18.0532	27.8214	
FITTER 2.0	17.0000	5.4863	1.6579	"	20.1418	21.9041	22.1138	9.2286	0.8939	1.1056	17.9146	27.6339	
HARTER	17.3819	4.9797	1.4822	"	19.7165	21.8840	22.1012	9.5514	0.9041	1.2025	18.0532	27.8214	

SAMPLE SIZE = 45, AGE = 12.5 YRS, 'a' = 0.999 x MnD

DAGOSTINO	17.4990	4.6495	1.2840	17.4990	18.9350	21.0040	22.0642	11.4148	0.9259	1.3054	17.9591	28.4258
WINDO	17.3819	4.9370	1.4385	"	19.5437	21.8634	22.0910	10.0034	0.9077	1.2344	18.0082	27.9675
WINDO	17.3819	4.9797	1.4822	"	19.7164	21.8840	22.1011	9.5514	0.9041	1.2025	18.0532	27.8214
FITTER 1	17.3819	4.9370	1.4385	"	19.5437	21.8634	22.0910	10.0034	0.9077	1.2344	18.0082	27.9675
FITTER 1.0	17.0000	5.4415	1.6090	"	19.9750	21.8762	22.0953	9.6366	0.8961	1.1285	17.8591	27.7612
FITTER 2	17.3819	4.9797	1.4822	"	19.7164	21.8840	22.1011	9.5514	0.9041	1.2025	18.0532	27.8214
FITTER 2.0	17.0000	5.4863	1.6579	"	20.1418	21.9041	22.1138	9.2286	0.8939	1.1056	17.9146	27.6339
HARTER	17.3819	4.9797	1.4822	"	19.7165	21.8840	22.1011	9.5514	0.9041	1.2025	18.0532	27.8214

APPENDIX 5

A.5 Kolmogorov - Smirnov (K-S) two sample test

The K-S test is very effective in finding out whether two samples of equal sizes have the same distribution pattern. It easily detects any significant difference, if any, between such samples. In this text, the K-S test has been used to test if there is any significant difference between the observed diameter distribution and the predicted diameter distribution from the Weibull parameters.

To carry out the test, the samples are first arranged in order of increasing magnitude using the same class width for the observed and the predicted diameter frequencies. The class width or interval could be in percentage of the total number of observations e.g. 5 percent per interval or in numerical value e.g 2 cm diameter class which has been used in this thesis. It has been recommended that the class width should be selected in such a way that the total

number of classes is not too few as this tends to reduce the sensitivity of the test (Campbell, 1972). The frequency of tree diameter in each class width is first recorded for both the observed and the predicted diameter data (see Table A.5.1). Next, the cumulative frequencies for the observed and the predicted number of trees per plot are calculated for each interval (see Columns 4 and 5 of Table A.5.1). To test if there is any significant difference between the observed and the predicted distribution, the largest value of the modulus which is 6 is compared with the figures in Table A.5.2 for the sample size, $n = 35$. At 5% significance level, the tabulated value is 11 and at 1%, this is 13. These values are higher than the largest modulus of difference of 6 obtained. Therefore, there is no significant difference between the observed and the predicted diameter distribution at both 1 and 5% levels.

It will be noted that Table A.5.2 gives values of the test statistics for maximum of sample size of 40. For sample size, $n > 40$, Steel et al. (1980) have given the following approximations.

- 1) At 5% level, the critical value (C.V) which is the value of the test statistic is given by:

$$C.V = 1.9206\sqrt{n}$$

- 2) At 1% level, the critical value is given by:

$$C.V = 2.1460\sqrt{n}$$

Table A.5.1 An example of the calculations* for the Kolmogorov-Smirnov (K-S) two-sample test.

Diameter Class (cm)	Frequencies		Cumulative frequencies		Absolute Difference
	Observed	Predicted	Observed	Predicted	
4-6	0	0	0	0	0
6-8	0	0	0	0	0
8-10	0	0	0	0	0
10-12	2	3	2	3	1
12-14	2	7	4	10	6
14-16	11	10	15	20	5
16-18	9	8	24	28	4
18-20	6	4	30	32	2
20-22	4	2	34	34	0
22-24	1	1	35	35	0
24-26	0	0	35	35	0

* Data were obtained from P. caribaea stand at Afaka at the age of 12.2 years and the predicted diameter distribution was based on the WWINGO subroutine of the multi-Weibull programs.

APPENDIX 5 (CONTD)

Table A.5.2 Values of test statistic required for 5 and 1 per cent significance levels in the Kolmogorov-Smirnov (K-S) two sample test (procedure described in A.5).

Sample size (n)	Significance level (per cent)	
	5	1
4	4	-
5	4	5
6	5	6
7	5	6
8	5	6
9	6	7
10	6	7
11	6	8
12	6	8
13	7	8
14	7	8
15	7	9
16	7	9
17	8	9
18	8	10
19	8	10
20	8	10
21	8	10
22	9	11
23	9	11
24	9	11
25	9	11
26	9	11
27	9	12
28	10	12
29	10	12
30	10	12
35	11	13
40	11	14

Source : Steel et al. (1980)

APPENDIX 6

Computer programs for estimating cumulative gamma distribution and plotting this and the various weibull cumulative distributions on common axes.

```

VGMFIT4[[]]V
VWP GAMPIT4 FN;P;V;CV;IS;NS;N;P;WPCX;YO;I;I;M;M;Y;E;K;Z;PA;SF;ALP;FIDDLE;PS
[1]  * ESTIMATING CUMULATIVE GAMMA DISTRIBUTION AND
[2]  * VARIOUS WEIBULL DISTRIBUTIONS FROM DATA IN FILE FN.
[3]  * DISTRIBUTIONS ARE PLOTTED ON COMMON AXES. 6/09/83
[4]  ALP+'ABCDEFGHIJKLMNPOQRSTUVWXYZ'
[5]  FN FTIE F+1+[0,FNUMS
[6]  S-'ENTER SUBFILE NAME.'
[7]  SP+1
[8]  'ENTER LENGTHS OF SUB-SUBFILES.'
[9]  NS+pCV+1
[10] * LET I RUN OVER SUB-SUBFILES. TO NS.
[11] SF+(SF=' ')/SP
[12] I+I+0
[13] PS+'*+*+'
[14] L0:=(0+pV+CFREAD F)/END
[15] +(0+pSF IN V)/L0
[16] V+CFREAD F
[17] V+CFREAD F
[18] V+CFREAD F
[19] L01:=(NS-I+I+1)/END
[20] Z+1;I+0
[21] L1:=(CV[I]≤pZ)∗(V/VcALP)V0=ppV+CFREAD F)/L2
[22] Z+Z,(V=0)/V+ZV
[23] →L1
[24] L2:N+pZ+Z[ΔZ]
[25] P=(AB BURGINO Z+(Z)/(Z)+(Z)/Z),1
[26] WPC+0,[0.5]0,WF WEIBULL2 Z
[27] YO+EDIST Z
[28] Y+(2,N)pJ+0
[29] Y[1;]+P ADJUST Z
[30] Y[2;]+WPC[2;]CUMWEIB Z
[31] E+(Y[1;]RMS YO),Y[2;]RMS YO
[32] K+(Y[1;]KS YO),Y[2;]KS YO
[33] L4:PA+Z,[1]YO,[1]Y
[34] →PS/L5
[35] ΔAV[13 28 32 10]
[36] 25 130 PLOT PA
[37] ΔAV[28 32 12]
[38] CAPTION
[39] 'GAMMA SCALE PARAMETER = ';P[1];' SHAPE PARAMETER = ';P[2];' LOCATION PARAMETER = ';FIDDLE
[40] (pZ);' OBSERVATIONS, FROM FILE ',FN,' SUBFILE ',SF,' CASE ';I
[41] WEIBULL A B C RMSE AGAINST DATA KS TEST AGAINST DATA'
[42] LEPT2,'5EB12.5'ΔPMT(WPC,E),K
[43] →L01
[44] L5:PRINT PA
[45] →L01
[46] END:ΔAV[13],'FINISHED.'
[47] PUNTIE F
V

```

APPENDIX 6 (CONTD)

```

VWEIBULL2[ ]V
VV+AB WEIBULL2 X;MU;SIGMA;TOL;LIM;I;PC;F1;F2;ALPHA;BETA
[1]  A ESTIMATION OF WEIBULL PARAMETERS
[2]  A VERSION FOR THE FORM OF NAYLOR AND OKOJIE
[3]  UL+10
[4]  LL+0
[5]  LIM+100
[6]  TOL+0.001
[7]  ALPHA+AB[1]
[8]  BETA+AB[2]
[9]  MU+MEAN X
[10] SIGMA+(SD X)*2
[11] PC+0,I+0
[12] V+1
[13] LOOP:+(LIM<I+I+1)/ERROR1
[14] +(V[1]>UL)/ERROR2
[15] +(V[2]<LL)/ERROR3
[16] +(^/(!(PC-V):V)<TOL)/PRINT
[17] PC+V
[18] F1+MU/:BETA
[19] V[1]+ALPHA+F1+:BETA
[20] F2+(12*BETA)-(1*BETA)*:BETA
[21] V[2]+BETA+(SIGMA:F2)+2*ALPHA
[22] -LOOP
[23] ERROR1:'ITERATION LIMIT OF';LIM;' EXCEEDED.'
[24] +0
[25] ERROR2:'COEFFICIENT A>';UL
[26] +0
[27] ERROR3:'COEFFICIENT B<';LL
[28] +0
[29] PRINT:I;' ITERATIONS.'
[30] V[1]+V[1]+-:V[2]
V
VMSAN[ ]V
VM+MEAN X
[1]  M+(/X):-1+pX
V
VSD[ ]V
VS+SD X
[1]  S+(MEAN(X-MEAN X)*2)*0.5
V
LEPT2
+ GAMMA
* WEIBULL

```

APPENDIX 7(a)

Weibull parameters and stand attributes for E. cloeziana

A	b	c	Age	MnD	MD	Dq	Dd	Dmax	BA	H	SIP1	SIP2	Hd
3.5E-7	12.43	3.54	4.20	4.00	11.20	11.70	16.80	17.40	10.90	1006	3.48	0.827	14.60
8.9E-7	16.09	4.48	5.60	4.80	14.60	15.10	20.40	22.60	13.94	782	2.98	0.532	16.70
2.7E-7	19.34	4.46	8.20	5.70	17.60	18.20	24.20	26.40	19.97	765	2.66	0.324	21.80
7.1E-7	21.43	4.60	10.50	7.00	19.60	20.20	26.40	28.30	23.15	723	2.50	0.239	26.30
8.27E00	16.22	4.27	12.50	13.40	23.00	23.40	28.50	30.60	23.86	557	2.22	0.177	27.80
8.77E00	17.64	4.37	15.50	15.00	24.80	25.20	30.30	33.10	25.69	515	1.94	0.125	28.50
1.32E00	10.77	3.05	4.20	4.40	10.90	11.50	16.60	17.90	11.36	1098	3.60	0.856	15.10
1.94E-6	15.20	4.87	5.60	6.40	14.20	15.00	19.60	21.30	14.08	798	3.05	0.545	17.10
7.3E-7	19.31	4.46	8.20	6.60	17.60	18.20	24.20	26.70	20.71	798	2.74	0.335	22.50
2.28E-6	21.18	4.39	10.50	6.60	19.30	19.90	26.70	29.00	24.64	790	2.51	0.239	26.40
8.83E00	15.46	3.93	12.50	14.00	22.90	23.20	28.50	31.20	25.03	590	2.22	0.178	27.80
7.42E00	18.64	4.33	15.50	14.00	24.40	24.80	30.70	33.10	28.09	582	1.95	0.126	28.70
1.73E-6	13.16	4.32	4.70	4.10	12.00	12.40	15.60	19.10	11.20	922	3.34	0.711	15.70
2.3E-7	16.46	4.03	6.50	4.40	14.30	15.50	21.00	24.20	16.69	883	3.08	0.473	20.20
3.2E-7	19.77	4.94	8.50	5.40	18.10	18.60	24.20	28.30	19.44	712	2.60	0.306	22.10
8.8E-7	12.63	3.56	4.70	4.00	11.40	11.90	15.20	18.80	10.35	927	3.23	0.688	15.20
1.43E-7	15.98	3.33	6.50	4.00	14.30	15.10	21.50	25.10	16.15	900	3.20	0.492	20.80
1.35E-7	19.18	3.51	8.50	5.70	17.20	18.10	25.30	28.30	19.52	756	2.71	0.318	23.00

(I T H O) V A T

APPENDIX 7(b)

Weibull parameters, stand attributes and site factors for E. tereticornis

No*	a	b	c	Age	MnD	MD	Dq	Dd	Dmx	BA	Hd	N	SIF1	SIF2	SD	RF	RD	T
1	8.93E00	6.18	2.96	6.3	10.2	14.4	14.6	17.8	19.7	11.91	18.8	712	2.98	0.474	95	1077	170	650
2	9.24E00	6.82	2.85	7.3	10.5	15.3	15.5	19.1	22.6	13.43	20.7	712	2.84	0.388	95	1077	170	650
3	1.465E+1	4.89	1.92	9.25	14.9	19.0	19.1	22.3	28.3	11.99	21.5	416	2.32	0.251	95	1077	170	650
4	1.757E+1	4.8	1.54	12.5	17.5	21.7	21.9	25.6	34.0	15.66	24.3	416	1.94	0.156	95	1077	170	650
5	1.829E+1	5.54	1.58	14.5	18.5	23.3	23.5	27.7	36.9	18.06	27.4	416	1.89	0.1303	95	1077	170	650
6	1.82E-6	13.26	4.67	6.3	4.0	12.1	12.5	16.5	17.8	14.29	19.7	1166	3.13	0.496	95	1077	170	650
7	1.17E-6	14.07	4.68	7.3	4.1	12.9	13.2	19.0	19.4	16.08	20.7	1166	2.84	0.388	95	1077	170	650
8	8.4E-7	15.4	4.62	9.25	5.5	14.0	14.5	19.4	22.3	19.16	21.3	1166	2.3	0.249	95	1077	170	650
9	2.9E-7	17.08	4.41	12.5	5.4	15.6	16.1	22.1	25.4	23.5	24.1	1157	1.93	0.154	95	1077	170	650
10	2.01E00	15.62	3.79	14.5	6.0	16.1	16.7	23.3	26.7	25.02	25.8	1148	1.78	0.123	95	1077	170	650
11	1.54E00	13.41	8.26	6.3	9.5	14.1	14.3	16.5	17.8	8.47	19.0	527	3.02	0.479	95	1077	170	650
12	4.37E00	11.58	6.37	7.3	10.2	15.2	15.2	17.8	19.4	9.68	19.9	527	2.73	0.375	95	1077	170	650
13	1.273E+1	6.05	3.35	9.25	14.0	18.2	18.3	20.0	22.9	7.76	22.3	296	2.41	0.261	95	1077	170	650
14	1.379E+1	7.34	3.4	12.5	15.3	20.3	20.5	22.4	26.7	9.79	22.6	296	1.81	0.145	95	1077	170	650
15	1.34E+1	8.72	3.59	14.5	15.3	21.3	21.4	23.5	28.3	10.68	25.7	296	1.77	0.122	95	1077	170	650
16	1.81E00	11.33	4.53	4.7	4.8	12.2	12.4	16.2	18.8	12.92	16.8	1063	3.57	0.761	80	1290	180	600
17	1.41E00	14.26	4.18	7.1	4.8	14.4	14.8	20.0	23.2	18.12	18.7	1053	2.64	0.362	80	1290	180	600
18	3.74E00	13.91	3.18	10.5	6.0	16.2	16.8	23.1	28.6	23.04	21.4	1044	2.04	0.194	80	1290	180	600
19	1.115E+1	8.52	1.86	12.6	11.8	18.7	19.2	25.4	31.8	22.99	23.1	795	1.83	0.146	80	1290	180	600
20	1.115E+1	9.75	1.91	14.5	11.8	19.8	20.4	27.5	34.0	25.87	24.5	795	1.69	0.116	80	1290	180	600
21	1.51E-6	12.17	5.05	4.0	4.1	11.2	11.5	15.2	16.2	10.07	13.1	975	3.28	0.82	100	1290	180	600
22	1.65E-6	14.79	5.16	6.2	4.1	13.6	13.9	19.2	19.4	14.9	19.4	975	3.13	0.505	100	1290	180	600
23	1.83E-6	16.0	5.24	8.2	4.8	14.7	15.1	19.6	20.7	17.43	24.7	975	3.01	0.367	100	1290	180	600

* Refers to serial number of data set

APPENDIX 7(c)

Weibull parameters, stand attributes and site factors for P. caribaea

No	a	b	c	Age	MD	Dq	Dd	N	SIP1	SIP2	RF	SD	Hd	T	RD	BA	GSP	MnD	Dmx
1	1.34E-1	12.42	5.25	9.7	11.57	11.8	15.9	3280	1.22	0.126	1290	80	11.8	600	180	36.1	0.96	4.8	16.5
2	2.5E00	11.66	4.23	12.2	13.1	13.4	18.2	3280	1.2	0.098	1290	80	14.6	600	180	46.2	0.96	5.4	18.8
3	2.26E00	12.56	4.12	14.0	13.66	14.0	19.3	3246	1.18	0.084	1290	80	16.5	600	180	50.0	0.97	5.4	19.7
4	6.5E00	7.52	3.15	9.7	13.23	13.4	17.0	1639	1.33	0.137	1290	80	12.9	600	180	23.2	1.0	8.5	18.5
5	1.001E+1	7.28	2.9	12.2	16.5	16.7	20.4	1327	1.3	0.107	1290	80	15.9	600	180	29.0	1.24	12.0	21.6
6	1.001E+1	8.11	3.06	14.0	17.26	17.5	21.5	1327	1.28	0.092	1290	80	17.9	600	180	31.8	1.24	12.4	22.6
7	5.92E00	7.93	2.89	9.7	13.0	13.3	17.5	1275	1.28	0.132	1290	80	12.4	600	180	17.8	1.0	11.0	18.4
8	4.38E00	13.4	4.07	12.2	16.5	16.9	22.3	1275	1.18	0.097	1290	80	14.4	600	180	28.5	1.0	12.5	23.2
9	4.01E00	14.71	4.23	14.0	17.4	17.7	23.6	1275	1.19	0.085	1290	80	16.7	600	180	31.6	1.0	12.7	24.5
10	8.9E00	7.01	1.0	9.7	15.9	17.4	21.0	520	1.29	0.133	1290	80	12.5	600	180	10.9	1.0	8.9	22.3
11	1.05E+1	8.79	1.0	12.2	19.3	21.2	24.5	520	1.16	0.095	1290	80	14.2	600	180	16.1	1.0	10.5	25.1
12	1.05E+1	9.71	1.0	14.0	20.2	22.4	26.1	520	1.2	0.086	1290	80	16.8	600	180	17.8	1.0	10.5	28.0
13	4.96E00	6.93	2.63	9.7	11.1	11.4	16.8	3417	1.33	0.137	1290	80	12.9	600	180	34.9	1.0	6.0	17.5
14	7.99E00	6.77	2.44	12.2	14.0	14.2	19.4	2084	1.23	0.101	1290	80	15.0	600	180	33.2	1.64	8.9	21.6
15	7.65E00	7.0	2.76	14.0	14.8	15.0	20.6	2084	1.24	0.083	1290	80	17.4	600	180	37.0	1.64	8.9	22.0
16	2.48E00	12.38	4.32	9.7	13.75	14.1	18.8	1835	1.36	0.14	1290	80	13.2	600	180	28.5	1.0	7.6	19.4
17	5.07E00	13.9	5.52	12.2	17.9	18.1	22.1	1210	1.2	0.098	1290	80	14.6	600	180	31.1	1.52	12.1	22.9
18	5.68E00	13.99	5.2	14.0	18.6	18.8	23.0	1210	1.26	0.09	1290	80	17.6	600	180	33.5	1.52	12.7	24.2
19	2.24E00	14.15	5.23	9.7	15.3	15.5	19.7	1275	1.36	0.14	1290	80	13.2	600	180	24.1	1.0	9.8	20.1
20	2.2E-6	19.5	5.96	12.2	18.1	18.4	23.1	1230	1.18	0.097	1290	80	14.4	600	180	32.7	1.04	10.2	23.2
21	1.9E-6	20.2	5.83	14.0	18.7	19.1	24.1	1230	1.19	0.085	1290	80	16.7	600	180	35.1	1.04	10.2	24.2
22	1.098E+1	4.88	1.42	9.7	15.3	15.6	20.7	956	1.32	0.136	1290	80	12.8	600	180	18.4	1.0	11.1	21.0
23	1.312E+1	5.79	1.45	12.2	18.4	18.7	23.9	956	1.18	0.097	1290	80	14.4	600	180	26.4	1.0	13.4	25.1
24	1.4E+1	5.81	1.0	14.0	19.2	19.9	24.8	956	1.2	0.086	1290	80	16.8	600	180	28.7	1.0	14.0	26.1
25	5.02E00	7.771	2.88	9.7	11.9	12.2	18.1	3417	1.49	0.154	1290	80	14.4	600	180	39.8	1.0	6.0	18.8
26	7.21E00	9.37	3.15	12.2	15.6	15.9	21.8	1948	1.26	0.103	1290	80	15.4	600	180	38.6	1.75	0.9	23.2
27	7.77E00	9.63	3.99	14.0	16.4	16.6	23.3	1948	1.31	0.094	1290	80	18.3	600	180	42.5	1.75	9.5	24.5

APPENDIX 7(c) (CONTD)

No	a	b	c	Age	ND	Dq	Dd	N	SIF1	SIF2	RF	SD	Hd	T	RD	RA	GSF	MnD	Dm
23	1.0E-7	15.06	5.95	9.7	14.0	14.2	18.1	1991	1.32	0.136	1290	80	12.8	600	180	31.6	1.0	6.7	18.8
24	5.9E-7	17.7	5.75	12.2	16.4	16.7	21.4	1991	1.26	0.103	1290	80	15.4	600	180	43.6	1.0	8.0	21.6
30	1.9E-1	16.17	5.65	14.0	17.0	17.3	22.3	1991	1.32	0.094	1290	80	18.5	600	180	46.9	1.0	8.3	22.6
31	2.74E00	12.72	4.76	9.7	14.4	14.6	18.8	1457	1.42	0.147	1290	80	13.8	600	180	24.5	1.0	8.0	19.1
32	7.67E00	10.69	3.33	12.2	17.3	17.6	22.4	1412	1.24	0.101	1290	80	15.1	600	180	34.2	1.03	10.5	23.2
33	7.5E00	11.87	3.48	14.0	18.2	18.5	23.9	1412	1.25	0.089	1290	80	17.5	600	180	37.9	1.03	10.8	24.8
34	3.5E-6	15.8	7.47	9.7	14.8	15.0	17.4	936	1.31	0.135	1290	80	12.7	600	180	16.5	1.0	9.5	17.5
35	2.72E00	16.25	6.37	12.2	17.8	18.1	21.4	936	1.25	0.103	1290	80	15.2	600	180	23.9	1.0	12.7	21.6
36	8.75E00	10.87	3.79	14.0	18.6	18.8	22.6	936	1.28	0.091	1290	80	17.9	600	180	25.9	1.0	13.4	23.2
37	2.93E00	8.94	3.39	9.7	11.0	11.3	16.8	3896	1.47	0.152	1290	80	14.3	600	180	38.8	1.0	4.8	17.8
38	3.35E00	10.16	3.16	12.2	12.4	12.8	19.5	3896	1.3	0.106	1290	80	15.9	600	180	50.5	1.0	5.1	21.3
39	4.46E00	9.55	2.83	14.0	13.0	13.4	21.0	3861	1.28	0.092	1290	80	17.9	600	180	54.3	1.01	5.7	22.3
40	4.88E00	9.17	3.37	9.7	13.1	13.4	18.4	2030	1.31	0.135	1290	80	12.7	600	180	28.6	1.0	7.0	20.4
41	6.27E00	10.01	2.95	12.2	15.2	15.6	21.9	1952	1.17	0.096	1290	80	14.3	600	180	37.1	1.04	8.3	23.9
42	6.41E00	10.52	2.93	14.0	15.8	16.2	23.2	1952	1.19	0.085	1290	80	16.7	600	180	40.1	1.04	8.6	24.8
43	2.62E00	13.21	4.89	9.7	14.7	15.0	19.7	1366	1.49	0.154	1290	80	14.4	600	180	24.2	1.0	7.6	20.0
44	4.14E00	14.54	4.42	12.2	17.4	17.7	23.1	1366	1.33	0.109	1290	80	16.2	600	180	33.7	1.0	9.2	23.6
45	4.35E00	15.22	4.44	14.0	18.2	18.6	24.0	1366	1.4	0.1	1290	80	19.6	600	180	37.0	1.0	9.9	24.5
46	9.5E00	5.59	1.01	9.7	15.1	16.1	20.0	728	1.38	0.142	1290	80	13.4	600	180	13.8	1.0	9.5	21.3
47	1.236E+1	5.96	1.08	12.2	18.2	18.9	23.8	728	1.2	0.098	1290	80	14.6	600	180	20.0	1.0	12.4	26.1
48	1.34E+1	6.01	1.01	14.0	19.4	20.3	24.9	728	1.24	0.088	1290	80	17.4	600	180	22.4	1.0	13.4	26.7
49	1.066E+1	3.52	1.27	9.1	13.9	14.2	17.3	1661	1.33	0.146	1290	84	12.1	600	180	26.1	1.65	10.8	17.5
50	1.21E+1	4.37	1.0	12.7	16.5	17.0	20.7	1661	1.24	0.097	1290	84	15.7	600	180	36.5	1.65	12.1	20.7
51	4.53E00	15.1	5.47	14.6	18.5	18.7	22.4	1411	1.25	0.085	1290	84	18.3	600	180	38.7	1.94	12.7	22.9
52	1.638E+1	5.0	1.82	16.1	20.8	21.0	24.3	1245	1.17	0.073	1290	84	18.8	600	180	43.0	2.2	16.9	24.8
53	2.0E-8	17.73	5.06	9.5	16.3	16.7	22.9	1661	1.64	0.173	1570	200	15.6	1300	180	36.4	1.0	6.7	24.7
54	6.04E00	14.37	4.44	10.5	19.1	19.4	24.8	1044	1.63	0.155	1570	200	17.1	1300	180	31.0	1.59	10.2	26.7
55	6.86E00	19.84	4.27	18.2	24.9	25.4	32.7	1044	1.31	0.072	1570	200	23.8	1300	180	52.8	1.59	12.7	35.0
56	1.634E+1	12.53	2.94	20.1	27.5	27.8	34.2	817	1.27	0.063	1570	200	25.5	1300	180	49.7	2.03	18.4	36.3

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308

APPENDIX 7(c) (CONTD)

No	a	b	c	Age	MD	Dq	Dd	N	SIF1	SIF2	RF	SD	Hd	T	RD	BA	GSP	MnD	Dmx
57	3.67E00	11.87	2.82	8.4	14.2	14.8	21.0	989	1.39	0.165	1750	100	11.7	600	220	17.0	0.97	5.4	24.5
58	3.09E00	15.56	3.36	10.3	17.1	17.7	25.0	961	1.38	0.134	1750	100	14.2	600	220	23.6	1.0	6.4	28.0
59	6.02E00	14.48	3.04	12.7	19.0	19.5	27.0	896	1.37	0.108	1750	100	17.4	600	220	26.8	1.07	9.2	29.6
60	8.84E00	9.44	2.47	8.8	17.2	17.6	22.5	933	1.63	0.185	1750	120	14.3	600	220	22.7	1.0	10.1	26.7
61	1.362E+1	7.62	1.89	10.7	20.4	20.7	26.5	748	1.53	0.143	1750	120	16.4	600	220	25.3	1.25	14.3	31.2
62	1.43E+1	10.52	1.003	13.7	24.8	26.9	30.2	307	1.36	0.099	1370	80	18.6	1250	190	15.6	1.0	14.3	30.9
63	2.039E+1	11.13	1.007	16.7	32.1	33.9	36.0	283	1.35	0.081	1370	80	22.5	1250	190	23.6	1.08	21.0	40.1
64	2.378E+1	13.34	1.017	21.9	37.0	39.2	42.6	283	1.15	0.052	1370	80	25.2	1250	190	31.5	1.08	23.8	43.2
65	3.118E+1	8.89	1.02	27.0	40.0	40.9	43.4	260	1.03	0.038	1370	80	27.8	1250	190	33.2	1.18	31.2	43.9
66	8.6E00	3.93	1.01	10.9	12.5	13.1	15.9	1412	1.41	0.13	1750	60	15.4	600	220	17.9	1.29	8.6	15.9
67	2.5E-6	15.5	6.61	13.8	14.5	14.7	18.3	1412	1.17	0.084	1750	60	16.1	600	220	23.8	1.29	8.9	18.4
68	1.017E+1	7.77	4.64	15.7	17.3	17.4	19.9	914	1.2	0.076	1750	60	18.8	600	220	21.6	2.0	13.7	20.4
69	9.2E00	4.76	1.0	10.9	14.0	14.7	20.8	1412	1.39	0.128	1750	60	15.2	600	220	23.1	1.12	9.2	21.6
70	8.58E00	8.37	1.69	13.8	16.0	16.7	24.3	1412	1.32	0.096	1750	60	18.2	600	220	30.8	1.12	9.2	25.4
71	1.587E+1	4.7	1.06	15.7	20.5	20.9	25.9	831	1.29	0.082	1750	60	20.2	600	220	28.1	1.9	15.9	27.0
72	2.03E00	14.25	3.25	10.9	14.0	15.5	22.8	1495	1.56	0.143	1750	60	17.0	600	220	28.2	1.39	6.0	23.9
73	4.0E-8	18.14	3.74	13.8	16.4	17.1	24.5	1495	1.46	0.106	1750	60	20.1	600	220	34.3	1.39	6.4	24.5
74	1.711E+1	4.36	1.2	15.7	21.2	21.5	27.2	831	1.46	0.093	1750	60	22.9	600	220	30.0	2.5	17.2	28.6
75	1.88E-1	13.72	4.54	10.9	12.7	13.1	17.5	1412	1.38	0.126	1750	60	15.0	600	220	19.3	1.18	9.9	18.8
76	1.038E+1	4.44	1.06	13.8	14.7	15.3	20.8	1412	1.29	0.093	1750	60	17.8	600	220	25.6	1.18	10.4	23.9
77	1.425E+1	4.4	1.1	15.7	18.5	18.9	22.9	831	1.24	0.079	1750	60	19.5	600	220	23.2	2.0	14.3	26.7
78	7.38E00	5.59	1.42	10.9	12.5	13.0	18.8	1578	1.38	0.126	1750	60	15.0	600	220	20.8	1.47	7.6	20.4
79	8.6E00	5.76	1.0	13.8	14.4	15.5	20.7	1412	1.43	0.103	1750	60	19.7	600	220	24.5	1.65	8.6	23.2
80	1.299E+1	4.5	1.01	15.7	17.5	18.0	22.0	914	1.32	0.084	1750	60	20.7	600	220	22.6	2.54	13.0	23.9

APPENDIX 8(a - c)

Data of age and top height for E. cloeziana, E. tereticornis and P. caribaea

(a)		(b)		(c)											
<u>E. cloeziana</u>		<u>E. tereticornis</u>		<u>P. caribaea</u>											
Age (Yrs)	Hd (m)	Age (Yrs)	Hd (m)	Age (Yrs)	Hd (m)	Age (Yrs)	Hd (m)	Age (Yrs)	Hd (m)	Age (Yrs)	Hd (m)	Age (Yrs)	Hd (m)	Age (Yrs)	Hd (m)
4.2	14.6	6.3	18.8	9.7	14.4	12.7	15.7	6.7	11.6	3.7	6.0	3.7	6.3	3.7	5.6
5.6	16.7	7.3	20.7	12.2	15.4	14.6	18.3	10.9	15.0	6.5	10.2	6.5	11.5	6.5	10.4
8.2	21.8	9.3	21.5	14.0	18.3	16.1	18.8	13.8	19.7	7.9	11.3	7.9	12.2	7.9	10.9
10.5	26.3	12.5	24.3	5.7	7.7	5.8	11.0	15.7	20.7	10.1	14.2	10.1	13.6	10.1	14.7
12.5	27.8	14.5	27.4	9.7	12.8	6.5	11.2	18.0	19.1	12.0	15.4	12.0	14.3	12.0	17.2
15.5	28.5	6.3	19.7	12.2	15.4	9.5	15.6	6.2	8.0	3.7	5.5	3.7	5.6	3.7	5.7
4.2	15.1	7.3	20.7	14.0	18.5	10.5	17.1	7.7	9.5	6.5	10.5	6.5	10.8	6.5	10.7
5.6	17.1	9.3	21.3	5.7	8.3	18.2	23.8	10.9	13.7	7.9	11.8	7.9	11.7	7.9	11.7
8.2	22.5	12.5	24.1	9.7	13.8	20.1	25.5	12.9	15.1	10.1	13.8	10.1	14.3	10.1	15.5
10.5	26.4	14.5	25.8	12.2	15.1	6.2	8.8	15.0	16.7	12.0	14.6	12.0	16.5	12.0	17.7
12.5	27.8	6.3	19.0	14.0	17.5	8.4	11.7	6.2	8.3	3.7	5.9	3.7	6.2	3.7	5.6
15.5	28.7	7.3	19.9	5.7	7.5	10.3	14.2	7.7	10.2	6.5	11.7	6.5	11.8	6.5	11.2
4.7	15.7	9.3	22.3	9.7	12.7	12.7	17.4	10.9	13.2	7.9	11.9	7.9	12.2	7.9	12.0
6.5	20.2	12.5	22.6	12.2	15.2	5.9	9.9	12.9	14.7	10.1	14.4	10.1	13.9	10.1	16.9
8.5	22.1	14.5	25.7	14.0	17.9	8.8	14.3	15.0	15.6	12.0	16.0	12.0	17.2	12.0	17.9
4.7	15.2	4.7	16.8	5.7	8.6	10.7	16.4	6.2	8.4	3.7	6.3	3.7	5.9	17.9	25.6
6.5	20.8	7.1	18.7	9.7	14.3	13.7	18.6	7.7	10.7	6.5	11.5	6.5	11.3	17.9	23.4
8.5	23.0	10.5	21.4	12.2	15.9	16.7	22.5	10.9	14.5	7.9	12.2	7.9	11.8	17.9	23.4
8.5	21.3	12.6	23.1	14.0	17.9	21.9	25.2	12.9	15.5	10.1	13.6	10.1	13.3	17.9	21.3
10.5	22.8	14.5	24.5	5.7	7.6	27.0	27.8	15.0	18.4	12.0	14.3	12.0	16.0	17.9	21.2
5.1	14.0	4.0	13.1	9.7	12.7	6.7	8.5	6.2	8.7	3.7	5.6	3.7	5.6	14.9	21.2
7.2	16.0	6.2	19.4	12.2	14.3	10.9	15.4	7.7	9.8	6.5	10.8	6.5	10.4	12.9	20.7
		8.2	24.7	14.0	16.7	13.8	16.1	10.9	13.3	7.9	11.7	7.9	10.9	21.9	28.0
		7.6	24.3	5.7	8.7	15.7	18.8	12.9	15.8	10.1	14.3	10.1	14.7	15.0	21.4
		7.6	19.8	9.7	14.4	6.7	12.2	15.0	16.9	12.0	16.5	12.0	17.2	17.0	22.3
		8.6	25.4	12.2	16.2	10.9	15.2	3.7	5.1	3.7	6.2	3.7	5.7	29.0	25.2
		8.6	20.1	14.0	19.6	13.8	18.2	6.5	10.6	6.5	11.8	6.5	10.7		
		7.6	22.5	5.7	8.0	15.7	20.2	7.9	12.1	7.9	12.2	7.9	11.7		
		8.6	23.1	9.7	13.4	6.7	11.0	10.1	13.9	10.1	13.9	10.1	15.5		
		4.0	13.1	12.2	14.6	10.9	17.0	12.0	14.7	12.0	17.2	12.0	17.7		
		6.2	19.1	14.0	17.4	15.7	22.9	3.7	5.5	3.7	5.9	3.7	5.6		
		8.2	24.7	4.7	8.7	6.7	10.7	6.5	10.8	6.5	11.3	6.5	11.2		
		4.3	15.4	5.3	9.9	10.9	15.0	7.9	12.0	7.9	11.8	7.9	12.0		
		4.3	15.3	6.7	11.0	13.8	17.8	10.1	13.8	10.1	13.3	10.1	16.9		
		4.3	15.0	9.1	12.1	15.7	19.5	12.0	15.5	12.0	16.0	12.0	17.9		

APPENDIX 9

Appendix 9(a) Data for computing intercorrelations of stand variables for E. cloeziana.

No*	Age	Hd	MH	N	Dq	BA	SV	TBA	TV	Dd
1	4.2	14.6	12.5	774	12.6	9.7	45.0	10.96	49.3	16.8
2	8.2	21.8	19.4	765	18.2	20.0	133.4	21.30	137.7	24.2
3	10.5	26.3	25.6	549	21.7	20.3	170.2	24.42	191.0	26.4
4	15.5	28.5	27.9	516	25.2	25.7	240.0	31.61	274.3	30.3
5	4.2	15.1	13.4	799	12.5	9.8	45.0	11.40	48.4	16.6
6	8.2	22.5	20.2	799	18.2	20.8	139.0	22.40	142.4	24.2
7	10.5	26.4	25.5	591	21.7	21.8	184.0	26.24	205.5	26.7
8	15.5	28.7	28.3	582	24.6	28.1	265.0	33.02	291.6	30.7
9	4.7	15.7	13.0	929	12.4	11.1	45.2	11.10	45.2	15.6
10	6.5	18.7	16.9	929	15.4	16.81	91.0	16.81	91.0	21.0
11	8.5	22.1	20.4	713	18.6	19.4	130.2	20.91	130.2	24.2
12	4.7	14.6	12.2	944	11.8	10.4	40.1	10.40	40.1	15.2
13	6.5	20.8	19.1	944	15.0	16.1	87.0	16.10	87.0	21.5
14	8.5	23.0	20.5	756	18.1	19.5	128.0	20.61	128.0	25.3
15	10.6	22.8	20.5	818	19.5	24.5	168.5	24.50	168.5	27.3

Appendix 9(b) Data for computing intercorrelations of stand variables for E. tereticornis

No*	Age	Hd	MH	N	Dq	BA	SV	TBA	TV	Dd
1	4.3	15.4	14.0	737	11.6	7.9	37.7	10.1	42.9	14.4
2	6.3	18.8	17.7	737	14.6	11.8	77.7	14.0	82.9	17.8
3	7.3	20.7	19.4	416	16.5	9.0	65.1	15.6	101.5	19.1
4	9.25	21.5	20.9	416	19.1	11.9	68.7	18.5	125.1	22.3
5	12.5	24.3	23.7	416	21.9	15.68	123.8	22.3	165.2	25.6
6	14.5	27.4	25.7	416	23.6	17.9	162.0	24.5	198.4	27.7
7	4.3	15.3	13.0	1244	10.4	10.67	48.0	10.6	48.0	14.2
8	6.3	19.7	17.1	1184	12.4	15.0	95.8	15.0	95.8	16.5
9	7.3	20.7	17.3	1184	13.0	16.3	107.5	16.8	107.5	19.0
10	9.25	21.3	18.9	1184	14.3	19.7	129.7	19.7	129.7	19.4
11	12.5	24.1	21.0	1184	15.9	24.1	172.8	24.1	172.8	22.1
12	14.5	25.8	22.5	1184	16.5	25.1	197.6	25.1	197.6	23.3
13	3.7	15.2	14.3	962	11.2	9.42	38.2	10.42	38.2	13.1
14	7.1	19.0	18.4	962	15.3	17.6	109.3	18.6	109.3	18.4
15	10.5	20.4	18.8	815	17.3	20.4	131.6	23.4	143.3	21.3
16	12.5	21.6	20.2	815	18.2	21.5	150.9	24.5	153.1	22.7
17	14.5	22.8	21.4	815	19.6	24.6	184.0	27.5	186.2	24.5
18	3.7	15.8	14.3	1072	10.5	9.29	35.0	9.5	35.0	13.2
19	7.1	18.3	17.0	1072	14.2	16.9	104.2	17.22	104.2	18.4
20	10.5	21.5	19.6	777	18.6	20.7	141.2	23.42	149.4	21.6
21	12.5	23.0	21.1	777	18.8	21.5	158.6	24.22	167.0	22.7
22	14.5	24.3	22.8	777	19.7	23.6	186.1	26.32	194.3	25.1
23	3.7	16.1	13.7	1220	10.5	10.5	39.5	10.5	39.5	15.0
24	7.1	20.0	15.8	1220	14.2	19.4	108.4	19.4	108.4	21.6
25	10.5	21.4	19.0	888	17.8	21.9	143.4	24.35	159.7	23.5
26	12.5	23.4	20.7	888	19.6	26.6	187.3	29.09	203.6	27.5
27	14.5	25.7	22.2	888	20.7	29.7	232.3	32.19	248.6	29.5
28	8.7	25.4	19.8	846	14.3	13.6	87.0	16.3	94.9	19.2
29	8.7	20.1	15.9	1247	11.8	13.6	71.9	13.6	71.9	16.9
30	8.7	22.6	19.0	839	14.1	13.2	88.1	15.9	95.6	18.7
31	8.7	22.8	18.4	1232	12.0	13.9	72.4	13.9	72.4	17.1
32	8.7	20.4	17.1	1211	12.1	13.9	72.3	13.9	72.3	18.0

* Refers to serial number of data set.

APPENDIX 9 (CONTD)

Appendix 9(c) Data for computing intercorrelations
of stand variables for P. caribaea.

	No*	Age	HA	MA	N	Dq	BA	SV	TBA	TV	Dd
NIMBIA	1	5.9	9.9	8.7	915	12.7	11.7	40.9	11.7	40.9	17.5
	2	8.8	14.3	13.0	760	18.4	20.1	108.1	22.8	127.2	22.5
	3	10.7	16.4	15.3	760	20.5	24.7	158.9	27.42	179.0	26.7
	4	12.9	20.7	19.2	760	22.3	29.2	220.3	31.92	239.4	29.0
	5	6.2	8.8	6.6	970	11.1	9.73	31.6	9.73	31.6	16.5
	6	10.3	14.2	12.5	970	17.7	23.2	120.1	23.8	120.1	25.0
	7	12.7	17.4	14.8	915	19.4	27.0	162.9	27.0	162.9	27.0
	8	14.7	21.2	17.9	898	20.6	29.9	218.5	29.9	218.5	28.9
	9	18.0	21.3	20.0	831	22.2	32.2	244.7	36.9	273.1	26.2
	10	6.7	11.0	9.5	1495	11.8	15.8	55.0	17.5	55.9	16.2
	11	10.9	17.0	15.7	1495	15.6	28.1	171.9	29.8	172.8	22.8
	12	13.8	20.2	19.4	831	20.4	26.8	209.5	36.0	252.7	24.5
	13	18.0	22.9	21.9	831	23.1	35.0	270.6	44.2	313.83	27.6
	14	6.7	10.7	8.8	1412	10.2	11.5	33.0	12.4	33.8	12.7
	15	10.9	15.0	12.6	1412	13.0	18.9	71.5	19.8	57.2	17.5
	16	13.8	17.8	16.5	831	16.7	18.3	126.9	25.6	158.9	20.8
	17	18.0	23.4	21.7	831	20.1	26.5	192.8	39.5	224.8	24.4
	18	6.7	11.6	8.2	1578	9.5	11.3	30.5	13.7	32.5	13.4
	19	10.9	15.0	12.5	1578	13.0	20.8	78.2	23.2	80.2	18.8
	20	13.8	19.7	17.3	914	16.7	20.1	139.5	26.8	160.4	20.7
	21	18.0	26.0	21.9	914	18.9	25.7	180.2	32.4	201.0	23.2
22	15.0	21.4	19.3	1286	27.1	74.2	541.1	55.8	681.2	33.1	
23	17.0	22.3	18.9	1286	29.4	87.6	689.1	109.2	829.2	37.7	
24	9.5	15.6	14.6	1065	17.9	26.8	158.8	36.7	208.0	22.9	
25	10.5	17.1	14.8	1065	19.4	31.5	190.1	41.4	239.3	24.6	
26	18.2	25.8	22.7	817	26.8	46.1	388.8	63.0	495.4	32.7	
27	20.1	25.6	24.3	817	27.8	50.2	422.4	67.1	529.1	34.4	
28	4.7	8.7	5.6	1748	10.7	15.6	39.6	24.3	39.6	13.2	
29	9.1	12.1	10.3	1665	14.2	26.1	114.8	34.8	142.6	17.3	
30	12.7	15.7	14.7	1415	17.3	33.3	127.0	45.2	228.2	20.7	
31	14.6	18.2	16.5	1249	18.8	34.6	205.2	48.9	258.5	22.4	
32	17.9	19.1	16.8	1249	21.7	45.3	321.8	60.4	375.1	25.5	
33	7.8	9.5	8.3	1440	10.2	11.6	32.6	11.6	32.6	16.5	
34	11.1	13.7	12.3	1203	14.6	20.1	99.2	20.1	99.2	22.2	
35	15.0	16.7	14.7	1111	17.3	26.1	150.3	26.1	150.3	25.3	
36	7.8	9.8	8.2	1500	10.8	13.9	40.3	13.9	40.3	17.2	
37	11.1	13.3	12.1	1081	14.6	18.1	96.8	18.1	96.8	22.2	
38	15.0	16.2	14.7	1141	17.3	26.8	150.5	26.8	150.5	25.1	
39	9.7	11.8	10.8	3281	12.1	35.9	135.9	35.9	135.9	15.9	
40	14.0	16.5	14.4	3281	13.9	49.7	249.2	49.7	249.2	19.3	
41	9.7	13.2	12.5	1132	15.5	21.4	104.3	29.6	129.8	18.8	
42	14.0	17.7	16.4	1210	18.7	33.4	202.1	41.6	227.6	23.0	
43	9.7	13.8	11.9	1412	14.6	23.5	101.2	23.5	101.2	13.8	
44	14.0	17.5	16.0	1412	18.5	38.0	223.2	38.0	223.2	23.9	
45	9.7	13.4	12.7	728	15.6	13.8	61.2	13.8	61.2	20.0	
46	14.0	17.3	16.9	728	19.8	22.5	137.9	22.5	137.9	24.9	
47	9.7	12.9	11.5	2358	11.4	27.1	102.6	36.7	127.2	16.8	
48	14.0	17.4	15.6	2085	15.0	37.0	212.1	46.6	236.7	20.6	
49	9.7	12.8	11.9	1991	14.3	32.7	178.6	32.7	178.6	18.1	
50	14.0	18.5	16.3	1991	17.3	46.9	270.3	46.9	270.3	22.3	
51	9.7	12.4	10.5	1276	13.4	17.9	70.0	17.9	70.0	17.5	
52	14.0	16.6	14.1	1276	17.8	31.6	169.4	31.6	169.4	23.6	
53	9.7	12.8	11.8	936	15.6	17.9	77.2	17.9	77.2	20.7	
54	14.0	16.8	15.6	936	19.5	28.0	164.5	28.0	164.5	24.8	

* Refers to serial number of data set.

APPENDIX 10

Appendix 10(a) Durbin - Watson statistic table.
Significance points of d_L and d_U : 5%

n	k' = 1		k' = 2		k' = 3		k' = 4		k' = 5	
	d_L	d_U								
15	1.08	1.36	0.95	1.54	0.82	1.75	0.69	1.97	0.56	2.21
16	1.10	1.37	0.98	1.54	0.86	1.73	0.74	1.93	0.62	2.15
17	1.13	1.38	1.02	1.54	0.90	1.71	0.78	1.90	0.67	2.10
18	1.16	1.39	1.05	1.53	0.93	1.69	0.82	1.87	0.71	2.06
19	1.18	1.40	1.08	1.53	0.97	1.68	0.86	1.85	0.75	2.02
20	1.20	1.41	1.10	1.54	1.00	1.68	0.90	1.83	0.79	1.99
21	1.22	1.42	1.13	1.54	1.03	1.67	0.93	1.81	0.83	1.96
22	1.24	1.43	1.15	1.54	1.05	1.66	0.96	1.80	0.86	1.94
23	1.26	1.44	1.17	1.54	1.08	1.66	0.99	1.79	0.90	1.92
24	1.27	1.45	1.19	1.55	1.10	1.66	1.01	1.78	0.93	1.90
25	1.29	1.45	1.21	1.55	1.12	1.66	1.04	1.77	0.95	1.89
26	1.30	1.46	1.22	1.55	1.14	1.65	1.06	1.76	0.98	1.88
27	1.32	1.47	1.24	1.56	1.16	1.65	1.08	1.76	1.01	1.86
28	1.33	1.48	1.26	1.56	1.18	1.65	1.10	1.75	1.03	1.85
29	1.34	1.48	1.27	1.56	1.20	1.65	1.12	1.74	1.05	1.84
30	1.35	1.49	1.28	1.57	1.21	1.65	1.14	1.74	1.07	1.83
31	1.36	1.50	1.30	1.57	1.23	1.65	1.16	1.74	1.09	1.83
32	1.37	1.50	1.31	1.57	1.24	1.65	1.18	1.73	1.11	1.82
33	1.38	1.51	1.32	1.58	1.26	1.65	1.19	1.73	1.13	1.81
34	1.39	1.51	1.33	1.58	1.27	1.65	1.21	1.73	1.15	1.81
35	1.40	1.52	1.34	1.58	1.28	1.65	1.22	1.73	1.16	1.80
36	1.41	1.52	1.35	1.59	1.29	1.65	1.24	1.73	1.18	1.80
37	1.42	1.53	1.36	1.59	1.31	1.66	1.25	1.72	1.19	1.80
38	1.43	1.54	1.37	1.59	1.32	1.66	1.26	1.72	1.21	1.79
39	1.43	1.54	1.38	1.60	1.33	1.66	1.27	1.72	1.22	1.79
40	1.44	1.54	1.39	1.60	1.34	1.66	1.29	1.72	1.23	1.79
45	1.48	1.57	1.43	1.62	1.38	1.67	1.34	1.72	1.29	1.78
50	1.50	1.59	1.46	1.63	1.42	1.67	1.38	1.72	1.34	1.77
55	1.53	1.60	1.49	1.64	1.45	1.68	1.41	1.72	1.38	1.77
60	1.55	1.62	1.51	1.65	1.48	1.69	1.44	1.73	1.41	1.77
65	1.57	1.63	1.54	1.66	1.50	1.70	1.47	1.73	1.44	1.77
70	1.58	1.64	1.55	1.67	1.52	1.70	1.49	1.74	1.46	1.77
75	1.60	1.65	1.57	1.68	1.54	1.71	1.51	1.74	1.49	1.77
80	1.61	1.66	1.59	1.69	1.56	1.72	1.53	1.74	1.51	1.77
85	1.62	1.67	1.60	1.70	1.57	1.72	1.55	1.75	1.52	1.77
90	1.63	1.68	1.61	1.70	1.59	1.73	1.57	1.75	1.54	1.78
95	1.64	1.69	1.62	1.71	1.60	1.73	1.58	1.75	1.56	1.78
100	1.65	1.69	1.63	1.72	1.61	1.74	1.59	1.76	1.57	1.78

n = number of observations.

k' = number of explanatory variables.

Source : Durbin and Watson (1951)

APPENDIX 10 (CONTD)

Appendix 10(b) A Table of Gamma Function

$$\text{Values of } \Gamma(\beta) = \int_0^{\infty} e^{-x} x^{\beta-1} dx; \Gamma(\beta+1) = \beta\Gamma(\beta)$$

β	$\Gamma(\beta)$	β	$\Gamma(\beta)$	β	$\Gamma(\beta)$	β	$\Gamma(\beta)$
1.00	1.00000	1.25	.90640	1.50	.88623	1.75	.91906
1.01	.99433	1.26	.90440	1.51	.88659	1.76	.92137
1.02	.98884	1.27	.90250	1.52	.88704	1.77	.92376
1.03	.98355	1.28	.90072	1.53	.88757	1.78	.92623
1.04	.97844	1.29	.89904	1.54	.88818	1.79	.92877
1.05	.97350	1.30	.89747	1.55	.88887	1.80	.93138
1.06	.96874	1.31	.89600	1.56	.88964	1.81	.93408
1.07	.96415	1.32	.89464	1.57	.89049	1.82	.93685
1.08	.95973	1.33	.89338	1.58	.89142	1.83	.93969
1.09	.95546	1.34	.89222	1.59	.89243	1.84	.94261
1.10	.95135	1.35	.89115	1.60	.89352	1.85	.94561
1.11	.94739	1.36	.89018	1.61	.89468	1.86	.94869
1.12	.94359	1.37	.88931	1.62	.89592	1.87	.95184
1.13	.93993	1.38	.88854	1.63	.89724	1.88	.95507
1.14	.93642	1.39	.88785	1.64	.89864	1.89	.95838
1.15	.93304	1.40	.88726	1.65	.90012	1.90	.96177
1.16	.92980	1.41	.88676	1.66	.90167	1.91	.96523
1.17	.92670	1.42	.88636	1.67	.90330	1.92	.96878
1.18	.92373	1.43	.88604	1.68	.90500	1.93	.97240
1.19	.92088	1.44	.88580	1.69	.90678	1.94	.97610
1.20	.91817	1.45	.88565	1.70	.90864	1.95	.97983
1.21	.91558	1.46	.88560	1.71	.91057	1.96	.98374
1.22	.91311	1.47	.88563	1.72	.91258	1.97	.98768
1.23	.91075	1.48	.88575	1.73	.91466	1.98	.99171
1.24	.90852	1.49	.88595	1.74	.91683	1.99	.99581
						2.00	1.00000

APPENDIX 11

Appendix 11(a) Observed and predicted standing volumes for E. cloeziana.

OBS*	AGE	N	BA	Hd	STANDING VOLUME	
					OBSERVED	PREDICTED
1	4.2	774	9.70	14.6	45.0	46.0
2	4.2	799	9.80	15.1	45.0	44.8
3	4.7	929	11.10	15.7	45.2	46.0
4	4.7	944	10.40	14.6	40.1	38.5
5	6.5	929	16.81	18.7	91.0	89.5
6	6.5	944	16.10	20.8	87.0	87.7
7	8.2	765	20.00	21.8	133.4	130.8
8	8.2	799	20.80	22.5	139.0	139.6
9	8.5	713	19.40	22.1	130.2	129.0
10	8.5	756	19.50	23.0	128.0	126.8
11	10.5	549	20.30	26.3	170.2	174.2
12	10.5	591	21.80	26.4	184.0	183.2
13	10.6	818	24.50	22.8	168.5	173.9
14	15.5	516	25.70	28.5	240.9	239.5
15	15.5	582	28.10	28.7	265.0	262.2

Appendix 11(b) Observed and predicted standing volumes for E. tereticornis

OBS*	AGE	N	BA	Hd	STANDING VOLUME	
					OBSERVED	PREDICTED
1	3.70	962	9.42	15.2	38.2	40.5
2	3.70	1072	9.28	15.8	35.0	34.3
3	3.70	1220	10.50	16.1	39.5	38.1
4	4.30	737	7.90	15.4	37.7	40.3
5	4.30	1244	10.67	15.3	48.0	47.7
6	6.30	737	11.80	18.8	77.7	73.0
7	6.30	1184	15.00	19.7	95.8	87.0
8	7.10	962	17.60	19.0	109.1	108.3
9	7.10	1072	16.90	13.3	104.2	98.7
10	7.10	1220	19.40	20.0	108.4	118.2
11	7.30	416	9.00	20.7	65.1	63.5
12	7.30	1184	16.80	20.7	107.5	101.4
13	8.70	846	13.60	25.4	87.0	96.3
14	8.70	1247	13.60	20.1	71.9	72.4
15	8.70	839	13.20	22.6	88.1	87.4
16	8.70	1232	13.90	22.8	72.4	83.0
17	8.70	1211	13.90	20.4	72.8	76.5
18	9.25	416	11.90	21.5	88.7	85.2
19	9.25	1184	19.70	21.3	129.7	122.5
20	10.50	815	20.40	20.4	131.6	134.3
21	10.50	777	20.70	21.5	141.2	141.4
22	10.50	888	21.90	21.4	143.4	147.0
23	12.50	416	15.68	24.3	128.8	127.2
24	12.50	1184	24.10	24.1	172.3	169.1
25	12.50	815	21.50	21.6	150.9	151.2
26	12.50	777	21.50	23.0	153.6	156.3
27	12.50	888	26.60	23.4	137.3	162.9
28	14.50	416	17.90	27.4	162.0	162.0
29	14.50	1184	25.10	25.8	197.6	191.0
30	14.50	815	24.60	22.8	134.0	187.6
31	14.50	777	23.60	24.3	186.1	185.9
32	14.50	888	29.70	25.7	232.3	232.2

* Refers to serial number of data set.

APPENDIX 11 (CONTD)

Appendix 11(c) Observed and predicted standing volumes for P. caribaea.

OBS *	AGE	N	BA	Hd	STANDING VOLUME	
					OBSERVED	PREDICTED
1	4.7	1748	15.60	8.7	39.6	41.0
2	5.9	915	11.70	9.9	40.9	41.1
3	6.2	970	9.73	8.8	31.6	26.3
4	6.7	1495	15.80	11.0	55.0	53.7
5	6.7	1412	11.50	10.7	33.0	29.3
6	6.7	1578	11.30	11.6	30.5	26.9
7	7.8	1440	11.60	9.5	32.6	28.2
8	7.8	1500	13.90	9.8	40.3	40.5
9	8.8	760	20.10	14.3	108.1	114.1
10	9.1	1665	26.10	12.1	114.8	113.7
11	9.5	1065	26.80	15.6	158.8	153.1
12	9.7	3281	35.90	11.8	135.7	136.4
13	9.7	1132	21.40	13.2	104.3	103.3
14	9.7	1412	23.50	13.8	101.2	111.4
15	9.7	728	13.80	13.4	61.2	68.2
16	9.7	2358	27.10	12.9	102.6	108.8
17	9.7	1991	32.70	12.8	178.6	149.2
18	9.7	1276	17.90	12.4	70.0	75.0
19	9.7	936	17.90	12.8	77.2	87.0
20	10.3	970	23.80	14.2	120.1	132.6
21	10.5	1065	31.50	17.1	190.1	194.7
22	10.7	760	24.70	16.4	158.9	159.1
23	10.9	1495	28.10	17.0	171.9	155.0
24	10.9	1412	18.90	15.0	71.5	85.7
25	10.9	1578	20.80	15.0	78.2	94.9
26	11.1	1203	20.10	13.7	99.2	97.0
27	11.1	1081	18.10	13.3	96.8	86.4
28	12.7	915	27.00	17.4	162.9	172.5
29	12.7	1415	33.30	15.7	187.0	184.0
30	12.9	760	29.20	20.7	220.3	215.7
31	13.8	831	26.80	20.2	209.5	184.2
32	13.8	831	18.30	17.8	126.9	107.7
33	13.8	914	20.10	19.7	139.6	123.8
34	14.0	3281	49.70	16.5	249.2	252.6
35	14.0	1210	33.40	17.7	202.1	203.8
36	14.0	1412	38.00	17.5	223.2	229.0
37	14.0	728	22.50	17.3	137.9	145.7
38	14.0	2085	37.00	17.4	212.1	201.2
39	14.0	1991	46.90	18.5	270.3	279.2
40	14.0	1276	31.60	16.6	169.4	184.0
41	14.0	936	28.00	16.8	164.5	173.8
42	14.6	1249	34.30	18.2	205.2	214.5
43	14.7	898	29.9	21.2	218.5	215.1
44	15.0	1286	74.2	21.4	541.1	552.0
45	15.0	1111	26.1	16.7	150.3	153.4
46	15.0	1141	26.8	16.2	150.5	154.9
47	17.0	1286	87.6	22.3	689.1	681.6
48	17.9	1249	46.3	19.1	321.8	306.8
49	18.0	831	32.2	21.3	244.7	234.5
50	18.0	831	35.0	22.9	270.6	268.2
51	18.0	831	26.5	23.4	192.8	195.2
52	18.0	914	25.7	26.0	180.2	194.1
53	18.2	817	46.1	23.8	388.8	379.6
54	20.1	817	50.2	25.6	422.4	433.8

* Refers to serial number of data set.

APPENDICES 12(a - c)

DIAMETER MODEL TESTING IN NEW STANDS :

COMPARISONS OF THE ACTUAL
AND PREDICTED CUMULATIVE DIAMETER
FREQUENCY DISTRIBUTIONS FOR

E. CLOEZIANA

E. TERETICORNIS

P. CARIBAEA

AT VARIOUS AGES

APPENDIX 12a

Comparisons of the actual and predicted cumulative frequency distributions from new stands of E. cloeziana at various ages.

1) AGE = 4.3 yrs a = 0.1094 b = 11.3527 c = 3.0939

Diam class (cm)	Actual cumulative freq. distribution (Act.Cum.Freq.Dist.)	Predicted cumulative freq. distribution (Pred.Cum.Freq.Dist.)	Absolute difference
4 — 6	14	16.2	2.2
6 — 8	34	36.6	2.6
8 — 10	52	63.2	11.2
10 — 12	74	90.4	16.4
12 — 14	103	111.6	8.6
14 — 16	123	124.2	1.2
16 — 18	132	129.8	2.2
18 — 20	132	131.5	0.5
20 — 22	132	132.0	0.0

K-S critical value at 5% level = 22; N.S.

11) AGE = 6.0 yrs a = 0.2018 b = 16.2198 c = 5.4578

Diam class	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 — 6	0	0.5	0.5
6 — 8	6	1.7	4.3
8 — 10	16	5.9	10.1
10 — 12	22	15.5	6.5
12 — 14	38	32.5	5.5
14 — 16	62	55.6	6.4
16 — 18	80	77.7	2.3
18 — 20	93	91.1	1.9
20 — 22	96	95.4	0.6
22 — 24	96	96.0	0.0

K-S critical value at 5% level = 19; N.S.

APPENDIX 12a (Contd)

111) AGE = 8.5 yrs $z = 0.0249$ $b = 19.7632$ $c = 6.5520$

Distn. class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 - 6	1	0.0	1.0
6 - 8	2	0.2	1.8
8 - 10	2	0.7	1.3
10 - 12	4	2.4	1.6
12 - 14	13	6.4	6.6
14 - 16	22	14.3	7.7
16 - 18	30	27.0	3.0
18 - 20	48	42.8	5.2
20 - 22	57	56.2	0.8
22 - 24	64	63.1	0.9
24 - 26	65	64.8	0.2
26 - 28	65	65.0	0.0

L_{25} critical value at 5% level = 15 ; H.S.

iv) AGE = 10.25 yrs $a = 0.1073$ $b = 21.9528$ $c = 4.0708$

Distn. class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 - 6	1	0.5	0.5
6 - 8	3	1.7	1.3
8 - 10	5	4.3	0.7
10 - 12	15	9.0	6.0
12 - 14	25	16.2	8.8
14 - 16	37	26.6	10.4
16 - 18	50	39.9	10.1
18 - 20	68	53.2	12.8
20 - 22	83	71.0	12.0
22 - 24	99	85.3	13.5
24 - 26	107	97.0	10.0
26 - 28	111	105.0	6.0
28 - 30	113	109.6	3.4
30 - 32	113	111.8	1.2
32 - 34	113	113.0	0.0

L_{20} critical value at 5% level = 20 ; H.S.

APPENDIX 12a (CONTD)

v) AGE = 10.5 yrs. $a=0.5301$ $b=21.0640$ $c=5.4823$

Diam. class (cm)	Act. Freq.	Cum. Dist.	Pred. Freq.	Cum. Dist.	Absolute Difference
4 - 6		0		0.0	0.0
6 - 8		1		0.2	0.8
8 - 10		1		0.8	0.2
10 - 12		1		2.2	1.2
12 - 14		7		5.3	1.7
14 - 16		15		10.8	4.2
16 - 18		21		19.3	1.7
18 - 20		34		30.6	3.4
20 - 22		47		42.9	4.1
22 - 24		57		53.5	3.5
24 - 26		62		60.2	1.8
26 - 28		64		64.0	0.0

K-S critical value at 5% level = 15; N.s.

APPENDIX 12b

Comparisons of the actual and predicted cumulative frequency distributions from new stands of E. tereticornis at various ages.

1) AGE = 4.0 yrs $a = 0.5953$ $b = 11.2515$ $c = 6.9654$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 _ 6	18	1.0	17.0
6 _ 8	45	8.8	36.2
8 _ 10	88	41.6	46.4
10 _ 12	147	111.3	35.7
12 _ 14	165	161.3	3.7
14 _ 16	167	166.8	0.2
16 _ 18	167	166.9	0.1
18 _ 20	167	167.0	0.0

L-S critical value at 5% level = 25 ; S.d. *

11) AGE = 4.3 yrs $a = 2.1756$ $b = 11.2915$ $c = 4.8521$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 _ 6	12	3.8	8.2
6 _ 8	28	15.5	12.5
8 _ 10	47	41.8	5.2
10 _ 12	92	79.7	12.3
12 _ 14	123	112.0	11.0
14 _ 16	128	125.6	2.4
16 _ 18	128	127.9	0.1
18 _ 20	128	128.0	0.0

L-S critical value at 5% level = 22 ; S.d. ...

APPENDIX 12b (Contd)

(11) AGE = 4.3 yrs $a = 0.7828$ $b = 12.26$ $c = 5.078$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 — 6	3	0.7	2.3
6 — 8	9	3.6	5.4
8 — 10	18	11.5	6.5
10 — 12	36	25.9	10.1
12 — 14	53	42.3	10.7
14 — 16	55	52.2	2.8
16 — 18	55	54.8	0.2
18 — 20	55	55.0	0.0

K-S critical value at 5% level = 14 ; N.S.

(17) AGE = 6.3 yrs $a = 9.72$ $b = 6.959$ $c = 2.712$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 — 6	0	0.0	0.0
6 — 8	0	0.0	0.0
8 — 10	0	0.0	0.0
10 — 12	3	1.6	1.4
12 — 14	14	8.0	6.0
14 — 16	26	18.0	8.0
16 — 18	33	27.2	5.8
18 — 20	34	32.1	1.9
20 — 22	34	33.7	0.3
22 — 24	34	34.0	0.0

K-S critical value at 5% level = 11 ; N.S.

APPENDIX 12b (Contd.)

(v) AGE = 7.6 yrs $a = 0.6472$ $b = 12.32$ $c = 4.3934$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 — 6	3	2.1	0.9
6 — 8	11	8.1	2.9
8 — 10	23	21.4	1.6
10 — 12	41	41.7	0.7
12 — 14	67	63.0	4.0
14 — 16	77	77.0	0.0
16 — 18	82	82.1	0.9
18 — 20	83	82.9	0.1
20 — 22	83	83.0	0.0

L_3 critical value at 5% level = 17 ; N.s.

(vi) AGE = 8.2 yrs $a = 0.2619$ $b = 15.1976$ $c = 5.7537$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 — 6	3	0.6	2.4
6 — 8	17	3.4	13.6
8 — 10	24	12.6	11.4
10 — 12	42	34.2	7.8
12 — 14	76	72.4	3.6
14 — 16	124	119.2	4.8
16 — 18	158	154.2	3.8
18 — 20	169	167.1	1.9
20 — 22	169	168.9	0.1
22 — 24	169	169.0	0.0

L_3 critical value at 5% level = 23 ; N.s.

APPENDIX 12c

Comparisons of the actual and predicted cumulative frequency distributions from new stands of P. caribaea at various ages.

i) AGE = 7.7 yrs $a = 4.8488$ $b = 8.1770$ $c = 3.0842$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 — 6	4	0.1	3.9
6 — 8	15	2.3	12.7
8 — 10	27	10.0	17.0
10 — 12	35	21.8	13.2
12 — 14	39	34.1	4.9
14 — 16	45	41.7	3.3
16 — 18	45	44.4	0.6
18 — 20	45	44.9	0.1
20 — 22	45	45.0	0.0

$K-S$ critical value at 5% level = 13 ; S.d. *

ii) AGE = 7.9 yrs $a = 3.6838$ $b = 13.781$ $c = 5.5769$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 — 6	0	0.0	0.0
6 — 8	0	0.1	0.1
8 — 10	1	1.0	0.0
10 — 12	7	4.8	2.2
12 — 14	30	14.8	15.2
14 — 16	63	33.9	29.1
16 — 18	78	58.2	19.8
18 — 20	82	75.7	6.3
20 — 22	82	81.4	0.6
22 — 24	82	82.0	0.0

$K-S$ critical value at 5% level = 17 ; S.d. *

APPENDIX 12c (Contd.)

(iii) AGE = 9.1 yrs $a = 3.0373$ $b = 15.508$ $c = 5.8798$

Diam class (cm)	Act. Cum Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 — 6	0	0.0	0.0
6 — 8	0	0.1	0.1
8 — 10	1	0.7	0.3
10 — 12	3	3.2	0.2
12 — 14	16	10.0	6.0
14 — 16	47	24.1	22.9
16 — 18	66	45.5	20.5
18 — 20	82	66.9	15.1
20 — 22	82	78.9	3.1
22 — 24	82	81.8	0.2
24 — 26	82	82.0	0.0

K-S critical value at 5% level = 17 ; S.L. =

(iv) AGE = 10.1 yrs $a = 3.840$ $b = 13.729$ $c = 4.4306$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 — 6	0	0.0	0.0
6 — 8	0	0.4	0.4
8 — 10	1	2.3	1.3
10 — 12	3	7.8	4.8
12 — 14	9	19.0	10.0
14 — 16	33	36.3	3.3
16 — 18	56	56.0	0.0
18 — 20	76	71.5	4.5
20 — 22	82	79.4	2.6
22 — 24	82	81.7	0.3
24 — 26	82	82.0	0.0

K-S critical value at 5% level = 17 ; N.S. ...

APPENDIX 12c (Contd)

(v) AGE = 10.25 yrs $a = 7.46$ $b = 7.6603$ $c = 2.257$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 — 6	0	0.0	0.0
6 — 8	1	0.1	0.9
8 — 10	5	3.2	1.8
10 — 12	17	10.8	6.2
12 — 14	23	20.7	2.3
14 — 16	34	30.0	6.0
16 — 18	38	36.7	1.3
18 — 20	40	40.5	0.5
20 — 22	42	42.2	0.2
22 — 24	43	42.8	0.2
24 — 26	43	43.0	0.0

K-S critical value at 5% level = 13 ; N.s.d.

(vi) AGE = 11.9 yrs $a = 8.0108$ $b = 11.037$ $c = 4.1443$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
4 — 6	0	0.0	0.0
6 — 8	0	0.0	0.0
8 — 10	0	0.0	0.0
10 — 12	0	1.1	1.1
12 — 14	4	6.0	2.0
14 — 16	20	18.0	2.0
16 — 18	47	37.7	9.3
18 — 20	69	58.9	10.1
20 — 22	77	72.6	4.4
22 — 24	78	77.2	0.8
24 — 26	78	78.0	0.0

K-S critical value at 5% level = 17 ; N.s.d.

APPENDIX 12c (Contd.)

(vii) AGE = 12.9 yrs $a = 15.6946$ $b = 6.96$ $c = 1.5583$

Dist. class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
12 — 14	0	0.0	0.0
14 — 16	6	0.6	5.4
16 — 18	12	13.3	1.3
18 — 20	30	30.5	0.5
20 — 22	44	46.6	2.6
22 — 24	57	59.3	2.3
24 — 26	65	68.2	3.2
26 — 28	75	73.9	1.1
28 — 30	79	77.2	1.8
30 — 32	83	79.1	0.9
32 — 34	83	80.1	0.1
34 — 36	81	80.6	0.4
36 — 38	81	81.0	0.0

 L_3 critical value at 5% level = 17 ; N.s.(viii) AGE = 14.7 yrs $a = 7.2798$ $b = 15.522$ $c = 3.6787$

Dist. class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
6 — 8	0	0.0	0.0
8 — 10	1	0.2	0.8
10 — 12	5	1.2	3.8
12 — 14	10	4.2	5.8
14 — 16	22	10.5	11.5
16 — 18	33	21.0	12.0
18 — 20	44	35.5	8.5
20 — 22	57	52.2	4.8
22 — 24	77	61.3	15.7
24 — 26	80	80.3	0.3
26 — 28	87	87.8	0.8
28 — 30	90	91.4	1.4
30 — 32	92	92.6	0.6
32 — 34	93	92.9	0.1
34 — 36	93	93.0	0.0

 L_3 critical value at 5% level = 18 ; N.s.

APPENDIX 12c (Contd)

(ix) AGE = 17.9 yrs $a = 15.2552$ $b = 5.536$ $c = 1.4978$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
10 — 12	0	0.0	0.0
12 — 14	1	0.0	1.0
14 — 16	5	2.5	2.5
16 — 18	15	15.3	2.3
18 — 20	30	28.5	1.5
20 — 22	38	38.4	0.4
22 — 24	44	44.8	0.8
24 — 26	48	48.5	0.5
26 — 28	49	50.4	1.4
28 — 30	51	51.3	0.3
30 — 32	52	51.7	0.3
32 — 34	52	51.9	0.1
34 — 36	52	52.0	0.0

K-S critical value at 5% level = 14 ; N.s.

(x) AGE = 21.9 yrs $a = 15.0631$ $b = 15.683$ $c = 3.5709$

Diam class (cm)	Act. Cum. Freq. Dist.	Pred. Cum. Freq. Dist.	Absolute difference
14 — 16	0	0.0	0.0
16 — 18	0	0.2	0.2
18 — 20	2	1.4	0.6
20 — 22	5	4.5	0.4
22 — 24	14	10.8	3.2
24 — 26	28	20.7	7.3
26 — 28	43	34.0	9.0
28 — 30	52	48.9	3.1
30 — 32	63	62.9	0.1
32 — 34	76	73.9	2.1
34 — 36	82	80.8	1.2
36 — 38	86	84.2	1.8
38 — 40	86	85.5	0.5
40 — 42	86	86.0	0.0

K-S critical value at 5% level = 18; N.s.