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The rates of diameter increment and age-diameter relationship of *Brachylaena huillensis* O. Hoffm in semi-deciduous forests of central Kenya

B. N. KIGOMO

Kenya Forestry Research Institute, PO Box 20412, Nairobi, Kenya

Summary

It is important to base yield regulations on recruitment of trees and their rates of growth to merchantable sizes. The present study investigated rates of growth of *Brachylaena huillensis* under its natural growing conditions.

The rate of diameter growth of *B. huillensis* is slow under natural conditions, ranging from 0·13 to 0·44 cm y^{-1} with a mean of 0·32 cm y^{-1}. Various possible factors contributing to the low rates of growth are suggested. The estimated growth rates over various diameter classes led to the construction of an age-diameter curve which indicated that, under natural conditions, a mean diameter of 40 cm dbh may be expected after 100 years, 45 cm after 130 years and 60 cm after about 175 years since regeneration.

Key words: *Brachylaena*, forest, increment, Kenya, rotation

Résumé

Il est important de baser les réglementations sur le terrain sur la repousse des arbres et leur de croissance avant d'atteindre une taille commercialisable. Cette étude a recherché le taux de croissance de *Brachylaena huillensis*, dans ses conditions de croissance naturelles.

Le taux d'accroissement du diaètre de *B. huillensis* est lent dans des conditions naturelles, il varie de 0,13 à 0,44 cm/an, avec une moyenne de 0,32 cm/an. On suggère différents facteurs qui pourraient contribuer à ce faible taux. Les estimations des taux de croissance pour des classes de différents diamètres ont permis d'établir une courbe ãge-diamètre qui montre que, dans des conditions naturelles, un diamètre moyen de 40 cm à hauteur de la poitrine peut ẽtre atteint après 100 ans, 45 cm après 130 ans et 60 cm environ 175 ans après la régénération.

Introduction

The accurate determination of forest and tree growth is of major importance to forest managers. Among several measurements, diameter increment has been used in studies which determine or predict parameters of stem and stand growth (see e.g. Newnham, 1962; Beck, 1974 & Daniels, 1976). Opie (1968) and Moore *et al.* (1973) used basal area to predict individual tree growth. Production of tree growth data from cores and discs of tree boles for analysis and prediction of growth is common (Brunner & Moser, 1973). However, it is not possible to determine rates of growth by counting growth rings for the majority of tropical trees as their growth rings are not easily distinguishable. For tropical trees, diameter and basal area remain the main parameters that have been used in predicting growth.

Rates of growth of species in mixtures show wide variations, especially in natural conditions. Problems associated with forecasting growth in irregular tropical forests are discussed by Dawkins (1956, 1958) and Beaton (1960) among other workers. Periodic increment in diameter has been found suitable for growth predictions of evolving stands. It is not strictly necessary to have long intervals between periodic measurements as long as a sufficient number of years is allowed to even out variations in the weather (Dawkins, 1958). A more critical point is the measurement of an adequate number of trees for every size-class.

It is necessary to determine diameter increments of *Brachylaena huillensis* O. Hoffm and therefore growth rate and possible rotation ages of the tree in natural forest conditions. The tree is currently the main commercially important species in the central and coastal forests, but has been seriously overcut, and its proper utilization to merchantable sizes and for continued supply of its wood in perpetuity requires some understanding on its growth dynamics. The present study therefore examines the stem diameter increment in *B. huillensis* under natural conditions and then attempts to determine an age–diameter relationship and possible rotation schemes.

Materials and methods

Study areas

The study was carried out in Dagoretti forest reserve, Karura and Ngong forests which lie around Nairobi City. The two main forest stations lie about the intersection 1·5°S and 37°E and are about 10 km apart. Karura is at 1790 m, and Ngong and Dagoretti at about 1860 m in elevation.

The three forest patches receive their peak rainfall in April and May. A short rainy season occurs between mid-October and early December but falls mainly in November. December to March is a fairly dry and hot period. A mean annual rainfall of 980 mm (30 years record) has been experienced.

Temperatures are reasonably equable with a mean annual of 24°C, minimum of about 11°C and maximum of 33°C at Karura. The soils are moderately deep sandy-loams to sandy-clay loams.

Field measurements

Individual trees of *B. huillensis* were identified and numbered in stands carrying the tree in the study forests. Trees of diameter at breast height (dbh) above 13 cm were numbered using aluminium labels in 1976. In 1982, more trees were included. In both years, labelled trees were recorded against their dbh and a remeasurement of all trees was done again in 1987.

In 1988, some 143 trees which were to be used in the analysis of periodic dbh increment had their 'crowding stress' assessed. The latter exercise was carried out by establishing 0·02 ha circular plots around the sample trees and counting all trees above 10 cm dbh within the plot. Only trees free of serious physical defects with nearly cylindrical boles and free of serious physical defects were selected for analysis. These were scattered randomly within stands in the study forests.

Table 1. Summary of estimated diameter increment of *B. huillensis* for three growth periods

1976–82		1982–87		1976–87	
Mid-class diameter	PMAI	Mid-class diameter	PMAI	Mid-class diameter	PMAI
33·7	0·24	16·1	0·30	34·7	0·26
34·9	0·20	17·8	0·29	36·2	0·24
36·0	0·37	19·9	0·32	37·7	0·26
37·5	0·17	23·1	0·29	39·0	0·32
38·9	0·28	26·2	0·28	40·3	0·23
40·2	0·23	29·1	0·40	42·2	0·32
41·1	0·35	33·6	0·36	43·4	0·26
42·2	0·36	37·4	0·26	46·2	0·22
43·0	0·29	40·1	0·39	49·1	0·36
45·6	0·28	42·5	0·37	52·4	0·22
49·5	0·29	45·9	0·29	55·1	0·23
64·2	0·13	52·4	0·44	61·7	0·35
66·2	0·44	67·5	0·31	77·3	0·21
Mean	0·28		0·33		0·27
SD	0·09		0·05		0·05
CV (%)	31		17		19

PMAI = periodic mean annual increment, SD = standard deviation, CV (%) = coefficient of variation.

Two incremental intervals, the first of 6 years and the second of 5 years were considered. Three periodic increments; 1976–1982, 1982–1987 and 1976–1987 were therefore available for growth analysis.

Data organization and analysis

For each growth period, trees were listed from the smallest to the largest and 'periodic annual increment' (PAI) of each tree size (dbh), obtained by dividing its periodic growth (cm) by the growth period (years), recorded against each tree size. For each growth period, the list of tree size (dbh) and its PAI was further divided into 'size classes (dbh)' of equal number of stems with the lower size class containing the smallest diameter trees and the upper size class containing the largest group of diameter trees. For each growth period and size-class, 'mid-class diameter' was obtained by taking the middle dbh within the range in each size class. Periodic mean annual increment (PMAI) for each mid-class diameter was estimated by computing the diameter increment from PAI for that class.

Estimates of diameter increments through size classes and derivation of age/diameter relationship were made using techniques described by Osmaston (1956) and Beaton (1960). By relating PMAI with mid-diameters of each size class, regression equations were obtained which estimated mean or smoothed rate of diameter increment for each diameter size class. This exercise produced PMAI against 10 cm diameter size classes and one other of 12 cm width.

To estimate the time (in years) taken by a member of a size class to grow through that particular size class, the width of the particular size class (10 cm or 12 cm) was divided by the corresponding PMAI. Starting from the lower limit of the lowest class, times of successive classes were determined. The obtained

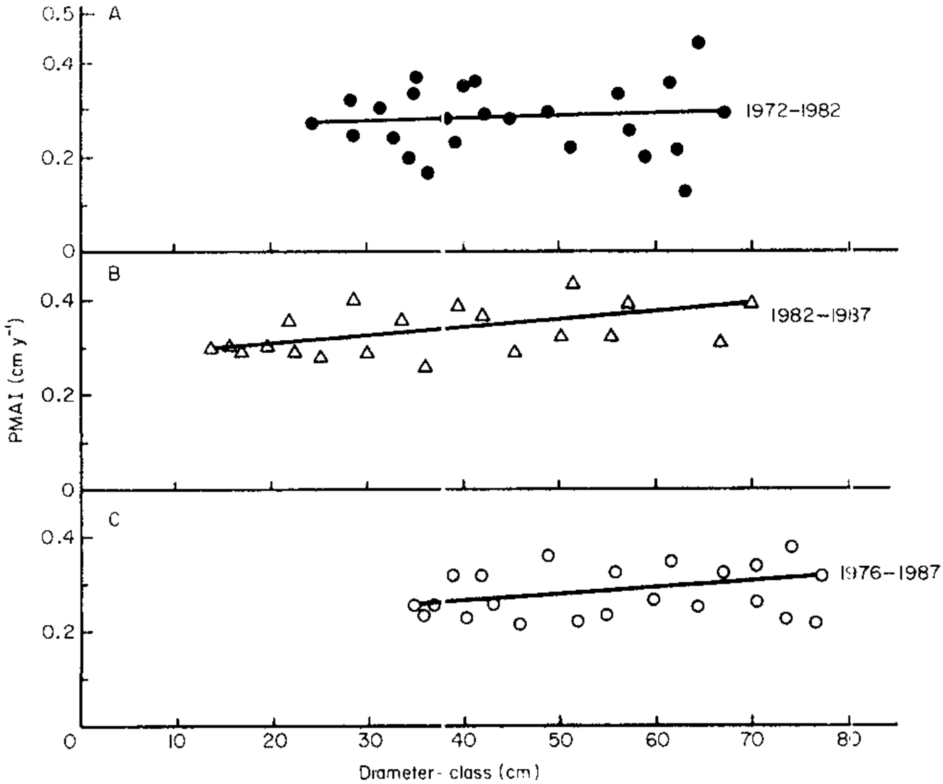

Fig. 1. Relationship between periodic mean annual increment (PMAI) and initial diameter in *B. huillensis* for three growth periods under natural conditions.

'times' were cumulatively added through successive classes. These sub-totals correspond to the time taken by a 'mean' tree to attain the size of successive class limits starting from the lower datum of smallest class. It is noted that in the absence of measurements below 15 cm dbh, it was presumed that the periodic increment curves follow the trend predicted by the equations in that range also.

Results and discussion

Selected study stems ranged from 14 cm to 92·1 cm dbh. Table 1 gives a summary of diameter increment by mid-size class diameters. Periodic mean annual increments in diameter for various diameter classes are relatively low, ranging from 0·13 to 0·44 cm y^{-1}. Periodic diameter increments show reasonably low coefficients of variation, the highest being 31 per cent (Table 1).

Poor relationships between periodic mean annual increment and initial mean diameter existed over the three growth periods. Figure 1 shows scatter graphs for the three growth periods. Several models of multiple regression analysis did not yield significant improvement of the linear regressions. Regressions of the 1972–1982, 1982–1987 and 1976–1987 growth periods explained only 2%, 12% and 3% variation of the periodic mean annual increment, respectively. It is possible that the slight difference between the r^2 for the 1982–1987 growth period and the other two may be attributed to the range of sample trees included in the

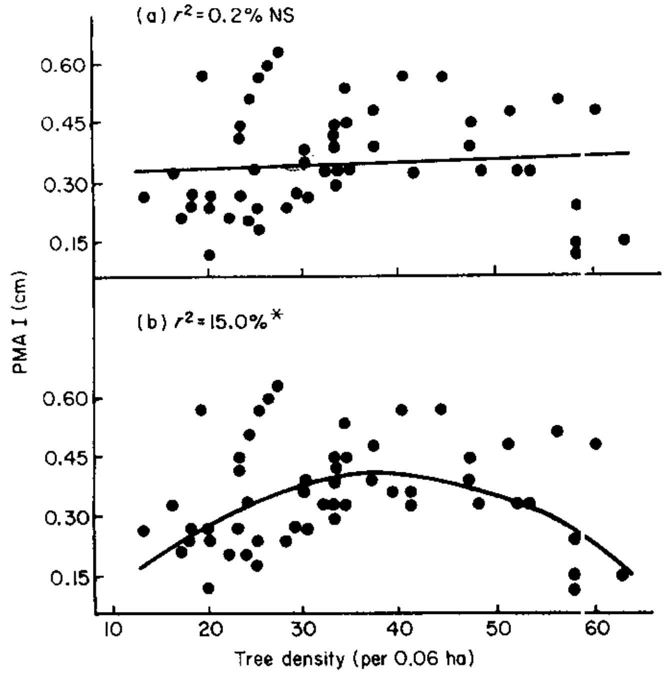

Fig. 2. Linear (a) and quadratic (b) relationships between mean annual increments (PMAI) and tree density in *B. huillensis*. *significant at 0·05 probability level.

growth analysis. The range was much wider foı this growth period than for the other two (Fig. 1).

A scatter diagram of the relationship between tree density and diameter increment (Fig. 2) indicates a poor linear relat onship. Logarithmic transformation did not prove strong enough to give any u:eful relationship (r^2=0·8%). The scatter, however, seemed to indicate a weak quadratic increment with low densities supporting low increment than low and l igh density plots. Using a polynomial regression analysis, a quadratic equati n was fitted, (PMAI= − 11·6+ 6·10 density − 0·873 $(\text{density})^2$, significant at th 5% probability level; r^2=15%.

The quadratic relationship may be explained by the fact that at low tree densities, open areas occur, resulting in a redu ed overall growth since the tree lives in shade, for most of its life. While 'opti num' crowding possibly creates conditions for better growth, higher densities may result in serious competition. Poor or lack of strong correlations between growth in diameter and density/tree size may also be attributed to complex interacti ıns among the particular species present in the mixed uneven-aged natural forests which may in turn result in limited and marked variations in freedom of gı owth.

Table 2 shows distribution of diameter by si:e class and the time, in terms of years, a mean tree within each size class takes tc pass through it. From the mean time of passage in years, an approximation o a diameter–age relationship is produced. Cumulative age estimate is related to the mid-diameter of each class to enable the production of the diameter–age cur e presented in Fig. 3.

The diameter–age relationship curve shows hat a natural regeneration of *B. huillensis* may attain 40 cm dbh in about 100 years (0·40 cm y^{-1}), 45 cm dbh in

Table 2. Diameter–annual increment trends of *B. huillensis* and estimated 'times' of passage and rotation age

Factors of Growth	Growth Periods	Diameter class (cm)					
		15–25	26–35	36–45	46–55	56–65	66–77
Width (cm)	1976–82	10	10	10	10	10	12
of diameter	1982–87	10	10	10	10	10	12
class	1976–87	10	10	10	10	10	12
PMAI	1976–82		0·28	0·28	0·28	0·29	0·30
(Fig. 2)	1982–87	0·31	0·32	0·34	0·35	0·37	0·39
	1976–87		—	0·27	0·28	0·29	0·31
Time of	1976–82	—	35·7	35·7	35·7	34·5	40·0
passage	1982–87	32·3	31·3	29·4	28·6	27·0	30·8
(years)	1976–87		—	37·0	35·7	34·5	38·7
Mean time of passage		32·3	33·5	34·0	33·3	32·0	36·5
Rotation age (y+)		32·3	65·8	99·8	133·1	165·1	201·6

y=the age of a 15 cm dbh tree.

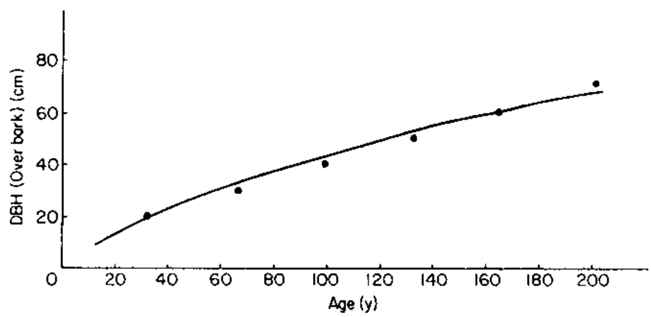

Fig. 3. Diameter–age curve of *Brachylaena huillensis* (muhugu) in natural conditions.

130 years (0·38 cm y^{-1}) or 60 cm dbh in approximately 175 years (0·34 cm y^{-1}) at its best rate of growth in natural conditions. This growth rate is fairly slow although this is not unique in tropical trees growing under natural conditions. Similar estimates of growth rate of *Shorea robusta* in Uttar Pradesh, India (Mathauda, 1958) indicated rotations of 120 years for species growing in a higher mean rainfall area (2500 mm) and 150 years in lower rainfall areas (1500 mm) to achieve 60 cm dbh. Rai (1987) estimated rotations of 214 and 178 years for *Dillenia pentagyna* and *Grewia tiliaefolia*, respectively, to attain 60 cm dbh, in a moist deciduous forest (annual rainfall 2500 mm) of Karnataka. Weaver (1979) gives estimates of rates of diameter increment ranging from 0·31 to 0·91 cm y^{-1} for trees growing in uneven tropical forests of Puerto Rico, Central America.

Growth in natural conditions where rainfall is limiting should be lower than the rates quoted above. Fernando (1962) estimated rates of growth between 0·23 and 0·32 cm y^{-1} for four trees; Satain, Ebony, Mila and Palm growing in dry zones in Ceylon. The rate of growth of *B. huillensis* estimated in this study is therefore reasonably high considering that the mean annual rainfall within the semi-deciduous dry forests of Kenya is only about 1000 mm.

The lack of free growth under natural conditions may explain, in part, the low rates of diameter increment of *B. huillensis*. Went (1957) concluded from his studies that shade-tolerant species are more competitive in shady environments through selection for low respiration rates and, hence, slow growth in all environments. *B. huillensis* flowers and produces profuse seed twice every year and is in flower almost continuously throughout the year. Energy investment into production may therefore be too much to allow a balance of energy enough to support fast growth, and this factor too may contribute to the low rates of growth indicated.

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