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CROWN-BOLE DIAMETER RELATIONSHIP OF JUNIPERUS PROCERA (CEDAR) AND ITS APPLICATION TO STAND DENSITY CONTROL AND PRODUCTION SURVEY IN NATURAL STANDS

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Juniperus procera Hochst. ex Endl (East African Pencil Cedar) is an indigenous evergreen dioecious timber tree belonging to the family Cupressaceae. It is a slow growing species but can attain a height of 36 metres. *Juniperus procera* is widely distributed in drier highland forests of Kenya from 1,100 to 2,500 m above sea level (a.s.l.) and mean annual rainfall of 1,000 to 1,350 mm (Dale and Greenway, 1961).

The Cedar crown is distinctly pyramidal in the early stages but spreads out with age. Due to its voluminous size, one tree can produce a relatively large quantity of timber although older trees are often piped due to heartrot fungus, *Fomes Juniperinus* Fr. The tree's heartwood and sapwood are well distinct both in appearance and utility. The sapwood is white, representing nearly two-thirds of the timber by volume in pole stage trees and is rapidly destroyed by termites. The heartwood is darkred, extremely resistant to termine attack and very durable in the ground.

Cedar timber has a wide use in building construction and joinery, roofing, fencing and telegraph posts. The widely utilized part of the wood is the heartwood (redwood) and with the current rate of population increase, its demand has risen so tremendously that measures have to be taken to utilize in perpetuity what may be remaining in the natural and small plantation stands. The current strategy is to improve through management the small plantation stands mainly distributed on escarpments and mountain range slopes and cedar crops occuring naturally.

Several constraints associated with Cedar management include its slow growth especially in natural stands, difficulties of natural regeneration, proportion of utilizable wood and stand density control. Its slow growth and nature of its crown development make it a good crop for environment protection especially on soil erosion prone areas.

The present study attempts to find ways of improving production per unit area through stand density control, to seek information on utilizable portions of the timber and to design a density control measure. The environmental protection objective is anticipated to be kept in force. A crown-bole diameter regression approach is anticipated to provide predictive estimates of maximum possible or limiting stocking in basal area. The said estimates are important in controlling competition among trees and therefore aimed at improving growth. The measure is also anticipated to provide a predictive equation of bole-diameter on crown diameter of use in general forest inventory and especially in the interpretation of aerial photographs of Cedar natural forests.

Materials and Methods

(i) *Study sites*

An attempt was made to cover a wide range of Cedar growing sites in terms of altitudinal and climatic conditions (Fig. 1). The five measured sites were:

Muguga—(1° 13′S, 36° 38′E)—Within lower altitude for the growth of Cedar. The sampling site lies about 20 km north-west of Nairobi. Measurements were taken from a 30-year-old arboretum crop of Cedar standing on a narrow ridge of land aligned roughly north and south and at 2,100 m a.s.l. Climate is equatorial, but because of the high altitude, essentially temperate with mean monthly maximum and minimum temperatures of 20.9°C and 10.8°C respectively. Mean annual rainfall is 968 mm, distributed bimodally with peaks in April and

November but annual totals are erratic and have varied from 571 to 1,515 over 31 years. Over most of the area, there is a deep (up to 5 m) layer of dark red, well drained, fertile volcanic loam soils derived from a recent volcanic parent soil.

Uplands—(Ngubi)—Situated 1° 02′S, 36° 38′E on an average elevation of 2,280 m a.s.l. Mean annual temperature and rainfall are 15.4°C and about 890 mm respectively. Rainfall comes mainly between mid-March and May with a short spell in November-December. Nearly all trees measured here were naturally growing openly and had fully developed crowns. The soil is well drained, dark reddish brown with light textured top soils, derived from both basement complex and recent volcanic rocks.

Elburgon—Situated 0° 18′S, 35° 48′E. Measured trees were growing on an average elevation of 2,380 m a.s.l. and experiencing mean annual temperature and rainfall of 14.7°C and 1,140 mm respectively. Rain falls between May and August. The measured trees were in a 58 year-old cedar plantation. Irregular tree crowns resulting from overlapping or damage from thinnings were excluded. Five trees were growing freely along the roadside. The forest soils are dark red sandy loams, reasonably well drained and derived from basement complex and volcanic rocks.

Timboroa—(0° 7′N, 35° 40′E) stand on an average elevation of 2,700 m a.s.l. Mean monthly temperature and annual rainfall are 13.6°C and 1,300 mm respectively. Rain falls from March to September but maximum rainfall occurs in May and August. Measured trees were sampled from a natural forest with scattered patches of Cedar regeneration. Both open and less openly growing trees were selected for measurement. The soils are dark brown clays with light textured drainable top soils on sloping land.

North Kinangop—Measured individuals were from natural regeneration of Cedar and showed free spreading crowns throughout their growth. Measured trees stood at an average elevation of about 2,715 m a.s.l. The mean monthly temperature and annual rainfall at this site are 12.6°C and 1,140 mm respectively. April and May are the main rain periods but lesser rainfall amounts are recorded in October and November. January to March is a dry period. Soils are strongly brown loams to dark greyish brown; they are highly humic as they are derived from volcanic ash.

(ii) *Data analysis*

A total of 198 trees had their crown and bole breast height diameters measured at the above measure sites. Breast height diameters (dbh) were taken at 1.3 m above the ground. Trees selected for measurement had symmetrical crowns. Crown diameter was estimated from three radii taken from about breast height to the edge of the crown. A two-metre rod was used to help the assessor in aligning himself vertically to the edge of the crown. Mean of the three radii multiplied by 2 estimated crown diameter. An attempt was made to cover measurements of a wide range of bole diameters and therefore crown sizes.

Measurements were grouped by sites (five) and regions (three) and each group subjected to simple regression analysis of bole diameters (x) on crown diameters (y). Regression lines were tested for similarities or parallelism or deviations from this by methods of Snedecor and Cochran (1973) and Dawkins (1968).

Crown diameter of various bole diameters were estimated from a pooled regression equation and corresponding crown: bole diameter ratios computed from the two parameters. Maximum attainable basal area by a cedar crop of various mean dbh was estimated from the formulae:

$$\frac{\text{Unit area (1 ha)} \times \text{Canopy density (1)}}{(\text{Crown: bole diameter ratio})^2} = \text{Basal area } (m^2/ha)$$

Where canopy density (1) apply to a crop at full canopy cover per unit area.

Bole/crown diameter relationship of Cedar was also estimated by regressing bole diameter on crown diameter.

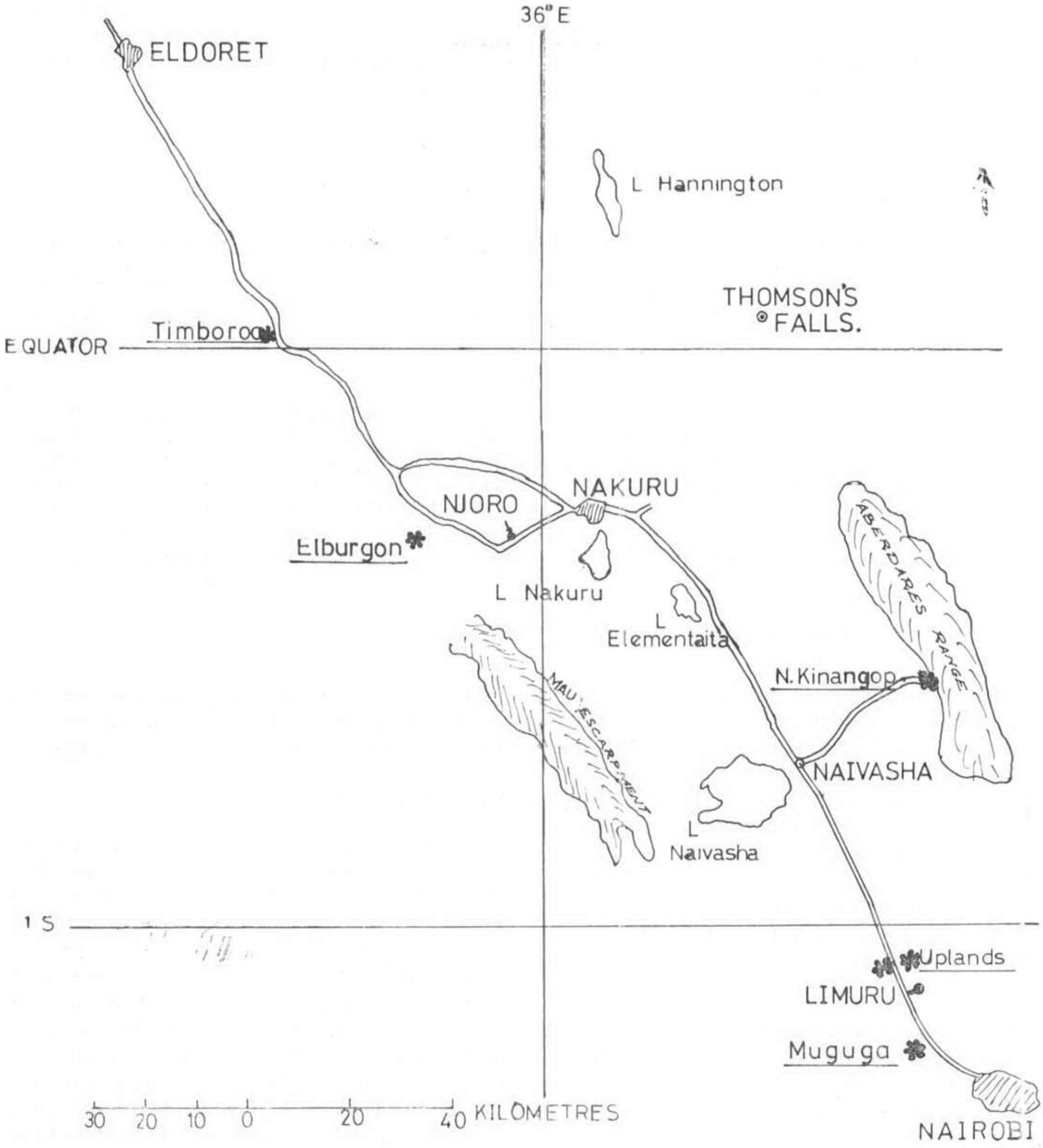

Fig. 1: Location of study site.

Results and Discussion

Measured bole dbh ranged from .06 to .93 m and crown diameter from 2.4 to 20.2 m. Table I gives regression equations for the five sites. All are significant at P=0.01. No significant difference among the five regression lines was found and as a result a pooled regression line was computed. This explained 87 percent of variation in crown diameters.

Table I—Regression Analysis of Cedar Crown/Bole Diameters from Five Growing Sites

Sites	Regression equations	Coefficients of determination (r^2)	F values	Degrees of freedom	S.E. of estimates
Timboroa.. ..	Y=1·17+21·29X	0·828	140·268***	(1·34)	0·913
Elburgon	Y=3·29+17·59X	0·622	34·811***	(1·24)	1·386
Uplands	Y=0·54+28·07X	0·769	94·206***	(1·31)	0·925
Muguga North ..	Y=2·76+18·99X	0·943	251·098***	(1·19)	1·056
North Kinangop..	Y=1·80+26·72X	0·827	371·293***	(1·84)	0·992
Pooled equation ..	Y=2·44+19·91X	0·866	982·699***	(1·196)	1·211

Where Y = Crown diameter (m) and X = DBH (m).

Regression equations of the regional data (sites of near similar altitudinal and climatic conditions, (i) North Kinangop, (ii) Muguga/Upland and (iii) Elburgon/Timboroa) gave no significant difference among them. Figure 2 shows the three regression lines and the pooled regression line which lies almost on the Muguga/Upland regression line. Explained variation of crown diameter in the three regional estimates are not significantly different from the explained variation by the pooled regression line.

The above results indicate that the estimated Cedar equation is not significantly affected by site. But constant "a" varies with site. This variation is an indication of "Plasticity" in crown diameter and therefore tolerance of crowding. Among crown plastic or crowding tolerant species the magnitude of "a" reflects intensity of the crowding factor; a high positive value of "a" is associated with a high density whereas a low or negative value of "a" is associated with sufficient growing space and crown development is unimpeded (Dawkins, 1963). This observation agrees with the present result in that, Elburgon and Muguga plantation crops which were more crowded gave higher "a" values. Openly growing trees measured at Upland, North Kinangop and Timboroa gave lower constant "a" values.

Stand Density Control

To improve production and quality of Cedar crops, individual trees in a stand must have unrestricted continuous freedom of growth. This requires knowledge of maximum or limiting stock carrying capacity of sites with time. Table II gives estimates of maximum possible carrying capacity in terms of basal area and stocking per unit area. An interesting figure in the table is the crown: bole diameter ratio of 23 of a Cedar crop of mean bole dbh of 60 cm. This ratio gives a maximum attainable basal area of 18.4 m^2 ha^{-1}. Dawkins (1963), after working with several tropical hardwood species came up with crown: bole diameter ratios ranging from 19-25. He noted that an average crown: bole diameter ratio of 20 permits tropical hardwood even-aged crops to attain 19-23 m^2 ha^{-1} of basal area without serious crown interferance. Mugasha (1980) working on *Ocotea usambarensis* Engl. got a ratio of 20.7 and Kwan Wong Yew (1966) got 17.5 with *Dyera costulata* Hk.f.

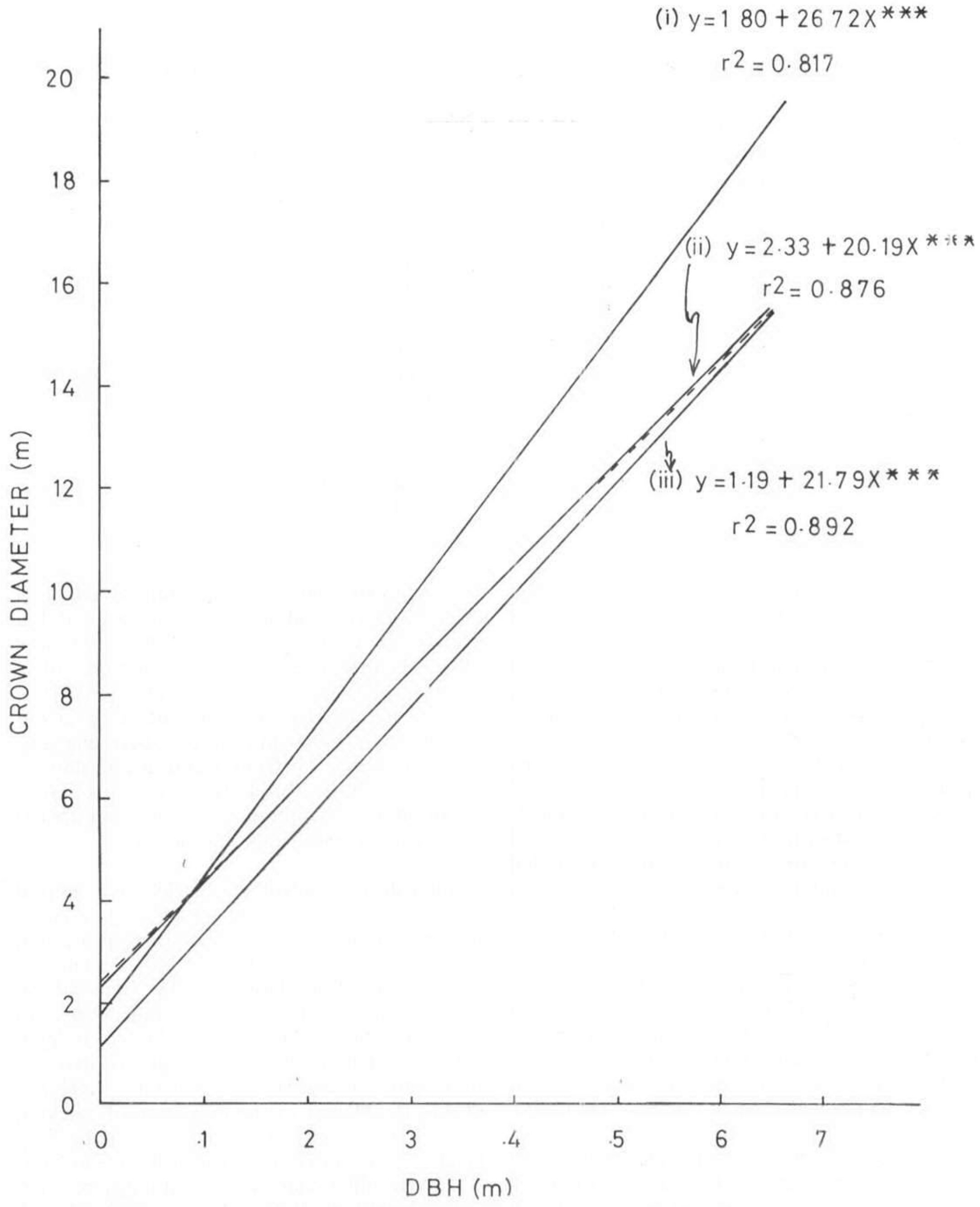

Fig. 2: Regression of crown diameter on bole diameter at breast height for 3 regions:
(i) North Kinangop line.
(ii) Uplands/Muguga line.
(iii) Timboroa/Elburgon line.

TABLE II—RELATIONS BETWEEN CEDAR CROWN: BOLE DIAMETER RATIO AND LIMITING BASAL AREA AND STOCKING

DBH OB (cm)	CD : BD ratio	Basal area (m^2ha^{-1})	Stocking (stems ha^{-1})
5	60	2·78	1,416
10	40	6·28	796
15	33	9·18	520
20	30	11·11	353
25	28	12·75	260
30	26·7	14·03	199
35	25·7	14·79	154
40	25·0	16·00	127
45	24·4	16·79	106
50	24·0	17·36	88
55	23·6	17·95	76
60	23·3	18·42	65
65	23·1	18·74	57
70	22·9	19·24	50

The above observation suggests that basal area of a managed Cedar crop may not exceed 18.4 m^2 ha^{-1} without crown overlapping and possible deterioration. Despite the plastic nature of Cedar crown observed in the present study, the tree deteriorates on overlapping, a common phenomenon among our plantation Cedar crops today. This may suggest that these crops may not be enjoying enough freedom of growth. A Cedar crown fire is more difficult to control (Mburu, 1971), than any other of our plantation species and with deteriorated crowns it would be more difficult to control.

The Bases of Stand Density Control in Cedar

The above crown-bole diameter regression may give biased predictive estimates of density control parameters for very young and old Cedar crops due to the sigmoid nature of growth development in plants. Care is therefore taken in interpreting the two extreme ends of the predictive equation. A young Cedar tree has a conical crown which spreads out with age. Such a crown morphology will enable a high photosynthetic surface area even when the canopy is touching as opposed to a flat spreading crown of the same age. Thogo and Dyson (1974) observed that a 14-year-old arboretum cedar crop took only four years after thinning for the canopy to close up. This suggests that a young crop of cedar is capable of responding to release even at the age of 20. It may therefore follow that loss of production due to delayed thinning of a young cedar crop may be minimized. The sigmoid nature of growth of cedar crop at old age indicates a maximum crown-bole diameter ratio of about 23 from stand mean dbh of 55 cm onwards (Table II). This is followed by an almost asymptotic curve of mean annual increment in basal area per hectare.

Silvicultural control of density in a natural stand with the aim of improving quality, production and at the same time protecting soil from erosion is difficult and demands a careful approach. This may be achieved by keeping the crop below competition levels and the approach followed here is by maintaining constant (Table II) basal areas, relative to maximum attainable at various stockings (Table II). Height as the only base of stocking control used today may be less reliable. Top height is not always uniform over several sites. A 20-year-old Cedar crop at Muguga reached a top height of 10.5 m (m.a.i.=0.53 m) and mean dbh 18.4 cm (Thogo and Dyson, 1974) whereas a 20.3-year-old Lushoto Cedar crop at almost the same stocking reached a height of 17.4 m (m.a.i.=0.86 m) and mean dbh of

17.9 cm (Mugasha, 1978). The differences seem too large to have occured by chance yet on the basis of top height one would go ahead and release the Lushoto crop with lower basal area and leave Muguga crop which shows a higher basal area and possibly undergoing competition. Age is less efficient than height as the only determinant of onset of requirement for release over wide plantation areas. Due to the wide climatic and altitudinal range of Cedar distribution, growth of Cedar varies between drier escarpment and plateau sites and the mountain range slopes.

The importance of managing for heartwood (redwood) proportion of the wood has been pointed out above. Measurements were carried out on felled sample trees from three sites to investigate the proportion of redwood to sapwood over various overback diameters (Fig. 3). At dbh overback of 66 cm, redwood volume was only 42 percent and the equivalent rotational diameter of redwood is about 49 cm coming at about age 110. For a normal rotational overback dbh of 50 cm, equivalent redwood diameter would be 35 cm at about age 80 (Table III). Longer rotational age is a constraint to production and replacing the crop with a younger faster growing crop may be feasible and economical. This means felling the crop at a rotational redwood dbh of about 35 cm. But should the current trend of offering higher premium for larger trees be compensatory enough, then keeping the crop to a dbh overback of 66 cm (about 49 cm redwood) may be justifiable. The argument of attack on old stems by *Fomes juniperinus* which leaves behind piped stems, two or more metres up the bole may be placed against keeping the crop to extreme ages.

TABLE III—RELATIONS BETWEEN OVERBACK AND REDWOOD (HEARTWOOD) DIAMETERS AND AGE

DBH–OB (cm) ..	5	10	15	20	25	30	35	40	45	50	55	60	65
DBH (cm) ..	0	1·2	5·1	9·4	13·6	17·8	22·1	26·5	30·7	34·9	39·9	43·6	47·6
Approx. age (years)	8	17	25	33	42	50	58	67	75	83	92	100	108

Estimate of mean annual increment in dbh of 0.6 cm to age 100 was made from results of ongoing permanent sample plots at North Kinangop, Timboroa and Elburgon. Plantation crops at these sites and Muguga arboretum give an average annual increment in dbh of 0.2 cm higher. A more free-growing natural Cedar may attain almost the same growth rate as observed with a 55-year-old sample plot 148 at Timboroa (Kigomo, in prep). An estimate of 0.6 cm may therefore be safe to work with in estimating ages of Cedar crops at various mean overback diameters (Table III). It should be noted that estimated ages are here used as a guide to the manager to check standing basal area of his crops rather than as an exact indicator of onset of competition.

Density Control Schedule

Table IV presents a feasible thinning schedule based on the knowledge of the maximum attainable basal area per unit area with age. For a Cedar plantation crop an initial espacement of 2.25 m−2.40 m may be feasible. Thinning is carried out at onset of maximum basal area limit thus avoiding possible later competition or loss of wood due to earlier creation of excessive spaces.

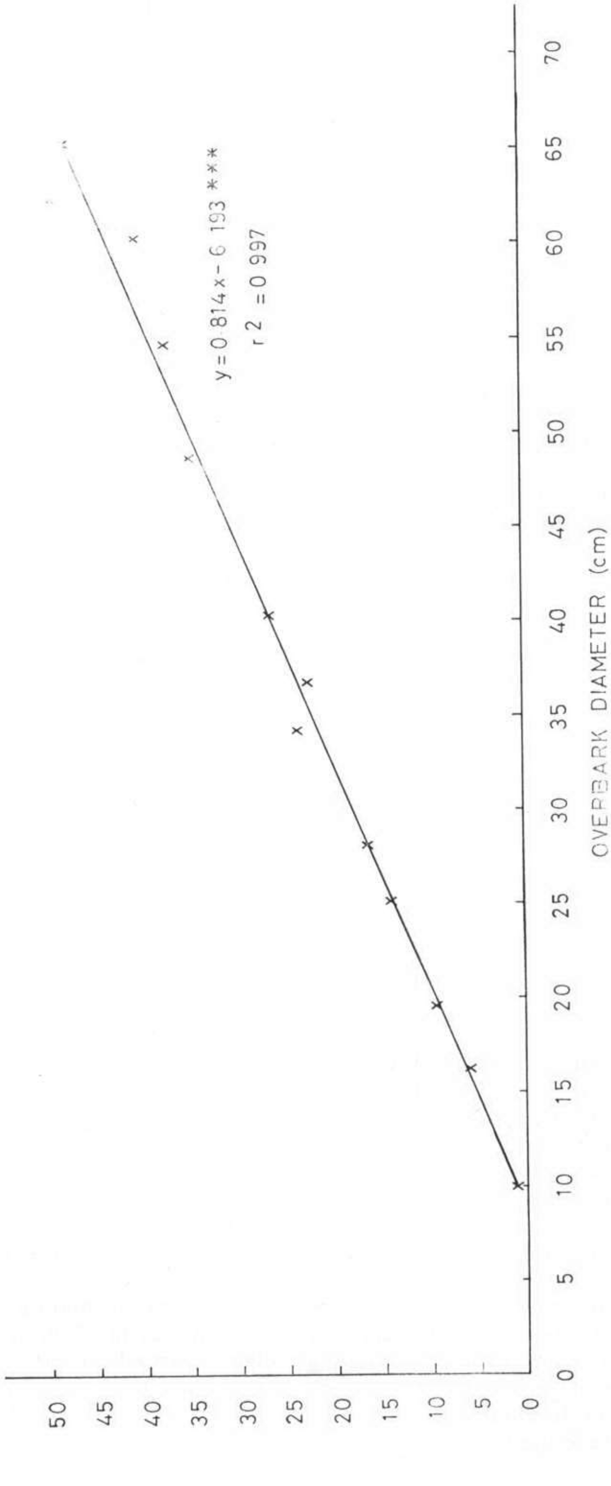

Fig. 3: Relationship of cedar heartwood with overback

TABLE IV—CEDAR STOCKING CONTROL REGIME

Age (years)	DBH OB (cm)	Basal area (m^2/ha) AT	Stocking Control (stems/ha)		Thinning cycle (years)	Thinning intensity %
			BT	AT		
17	10	6·28	2,000	800	—	60
25	15	7·24	800	410	8	49
33	20	9·42	420	300	8	28
42	25	11·04	300	225	9	25
54	31	11·69	225	155	12	30
67	40	14·44	155	115	13	26
83	50	17·36	115	90	16	22

BT = Before thinning AT = After thinning

Thinning intensity (%) = Basal area removed in terms of stems.

Open growing Cedar trees develop highly tappered, short bole, coarse branched stems. For this reason and the fact that the crop is capable of responding readily to thinning as pointed out above, first thinning can be delayed to about age 17. To avoid a possible windblow, the first density release should be selective undercrown thinning and intensity should be kept to the estimated carrying basal area capacity at the above age. Further thinning cycles should take care of proper utilization of space. Since older crops respond less readily to thinning treatments, thinning cycles become longer with age of the crop. Final thinning is at about age 80. Mean annual increment in basal area after this age is at its minimum and as pointed out above, felling can be undertaken at any time after this depending on the economics of the market.

Cedar requires a lot of light, especially in later stages of growth but will tolerate a certain amount of shading when young. Regenerating seedlings start from edges of openings. It does not regenerate adequately and in some sites it is difficult to find Cedar seedlings under its own canopy. Methods of encouraging regeneration should be investigated. These should include group exploitation techniques to create openings for regeneration and retaining of better seeder trees for a time or seed broadcasting. Floor cleaning and controlled fire treatment would possibly improve regeneration by removing impeding top litter. Once available, viable techniques should be employed to establish a second rotation crop before the final crop is clear felled.

Application of Cedar Bole/Crown Diameter Relationship to Cedar Inventory

Crown-bole diameter relationship developed by the present study can be used in estimating quantitatively the canopy dominance of a Cedar crop in a stand. Only dbh of Cedar trees in sampling units is required to estimate both basal and aerial phytosociological status of Cedar in a particular forest community.

Using the measured data from the five sites, a bole-crown diameter regression equation was computed (Fig. 4). Eighty-eight percent variation of bole diameter was explained by the crown diameter. This relationship would be useful in aerial photo-interpretation especially in the Cedar plantation and natural forests inventory where Cedar is a member of the stands. Measures of photo-crowns will estimate bole diameters from which estimates of production status of Cedar produce in a particular stand can be derived.

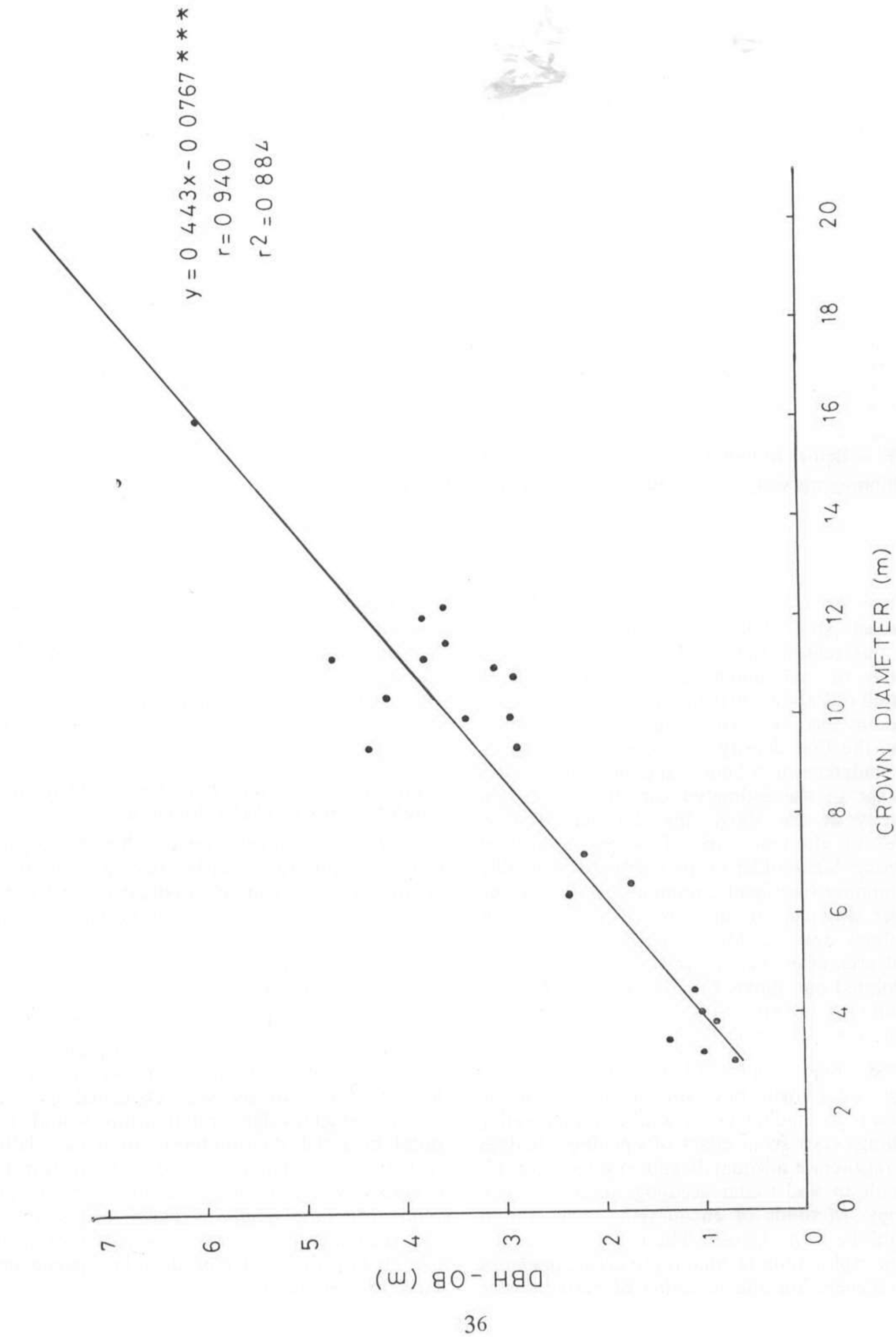

Fig. 4 : Regression of bole d.b.h. (o.b.) on crown diameter for 5 study sites

Conclusion

The current objectives of management of natural forests requires improvement of quality and yield and sustained production of growing stock in perpetuity (Mburu, 1979). This objectives can be achieved through proper understanding of our working material especially the main commercial timber trees. The present study directs its attention to *Juniperus procera* (Cedar), an indigenous tree species with a wide end produce utility down to the village level.

Present control of stand density in Cedar crops; a paramount important operation to the improvement of quality and yield is based on height only. This has limitations and its use as the only density controlling tool disregarding other stand development parameters is questionable. Basal area, as a density controlling parameter developed for Cedar in the present study, takes account of quantitative limitation of growth with age; its use in plantation and Cedar natural stands is recommended. Future incremental data likely to accrue from a few of the on-going permanent sample plots of Cedar is anticipated to improve estimates of thinning cycles used in the above schedule. Testing of the proposed density control schedule could best be done by properly monitored permanent sample plots.

Summary

Five sites were selected for measurements of *Juniperus procera* (Cedar) crown and bole diameters. Site equations of crown-bole diameter relationship were calculated from the data. With no significant difference noted among the five lines, a pooled linear regression equation $y=2.44+19.91X$, significant at $P=0.01$ was calculated. 87 percent variation of crown diameter was explained by corresponding bole diameters.

This study reveals that there exists a positive correlation between the bole and crown diameter of a Cedar tree which can be of practical use in the control of stand development of plantation and natural Cedar stands. The equation was used to estimate a stand density control parameter (basal area) and a thinning schedule of cedar stands developed.

Sustained production of Cedar produce from natural stands is difficult due to lack of easy regeneration of Cedar under its own canopy. Investigations aimed at developing techniques of improving natural regeneration are suggested.

A reverse relationship to the above between bole diameter on crown diameter was also calculated ($y=0.0443X-0.0767$, significant at $P=0.01$). This equation is important in aerial photo-interpretation of stands where Cedar is a bio-social component.

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