RELATIONSHIP BETWEEN THE CROWN WIDTH - DIAMETER RATIO

OF WHITE SPRUCE TREES AND STAND DENSITY, AGE, AND

SITE IN THE INTERIOR OF BRITISH COLUMBIA

(Project B. C. 25)

by

K. J. MITCHELL

FOREST RESEARCH LABORATORY

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INTERNAL REPORT BC-I

DEPARTMENT OF FORESTRY

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INTRODUCTION

British Columbia is very dependent on its forests, which are estimated to contain 320 billion cubic feet of accessible merchantable timber (Anon. 1962a). Approximately 1.3 billion cubic feet of forest products, valued at 800 million dollars, were cut in 1962 (Anon. 1963). The interior spruces, white (Picea glauca (Moench.) Voss.) and Engelmann (Picea engelmanni Parry), accounted for 16 per cent of the annual cut in the province and approximately 30 per cent of the merchantable timber.

The largest area of spruce is in the central and northern interior part of the province where white spruce is the most important species. Continued increase in the annual production is expected particularly when pulp mills come into operation.

Extensive forest management based on a regulated annual cut to ensure continuous yield, is being practised in the Prince George District in the form of Sustained Yield Units, Public Working Circles, and Tree Farms. More intensive management will likely develop as pulp mills create a market for small timber from intermediate cuttings.

Mensurational studies are being conducted to provide information relative to the growth of individual trees and include investigations concerned with growth in height, diameter and volume, changes in form, growing space requirements and the effects of competition. The importance and utility of tree crown information will be emphasized in this report and

in future studies.

Smith, Ker and Csizmazia (1961), Apsey (1961), Pearson (1962), and Johnson (1962) have shown good relationship between crown width and bole diameter at breast height (dbh) for open- and dense-grown Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), alder (Alnus rubra Bong.), black cottonwood (Populus trichocarpa Torr. and Gray) and Engelmann spruce. Density was found to influence the relationship much more than age or site quality. Bonner (1964) reported crown width and diameter (b.h.) of lodgepole pine (Pinus contorta Dougl.) were closely correlated but the relationship was not significantly affected by stand density. Vezina (1962) studied open-grown white spruce and balsam fir (Abies balsamea (L.) Mill.) and also found a good relationship between crown width and diameter (b.h.). This relationship appears to be generally accepted as it has been reported for many species. However, the influence of stand density, site quality and other factors upon the relationship has not been adequately investigated. The role of these variables should be understood before crown width - d.b.h. information is applied.

An immediate application of such studies is for forest inventory. Height and crown width, obtainable from aerial photographs, can be used to estimate tree volume if a sound relationship is established between crown width and stem diameter.

A knowledge of crown width-d.b.h. relationships would be of use in forest management. Smith, Ker and Csizmazia (1961) suggested that the ratio between the two parameters may be useful to assess density, growth and growing stock. Time and yield of thinnings could be forecast from expected crown width and bole diameter growth. A method for constructing yield tables has been developed which uses crown widths and the assumption of square spacing (Apsey 1961, Pearson 1961, Johnson 1962). Newnham (1964) used crown width-d.b.h. relationships to construct a stand model for predicting the growth and development of Douglas-fir. Numerous volume tables utilizing this relation-

ship have also been constructed.

The objective of this study is to determine how the crown-width and diameter at breast height of white spruce are related to age, site and competition from surrounding trees. Supplementary data pertaining to diameter growth at breast height, length of live crown and tree form provide additional information which will be reported separately.

DESCRIPTION OF THE STUDY AREA

LOCATION

The study area is located 10 miles northwest of Prince George (latitude 54° 05' N., longitude 122° 55' W.). Sampling of immature stands was centred in an area extending 15 miles east of the Hart Highway along the Chief Lake Road and five miles north. Twenty plots were established in mature stands two miles north of Summit Lake.

THE FOREST

Rowe (1959) classified the forests as being in the Montane Transition Section (M4) of the Montane Forest Region because of the scattered occurrence of Douglas-fir. White spruce and alpine fir (Abies lasiocarpa (Hook.) Nutt.) are the principal species. They occur as pure stands or associated with varying amounts of Douglas-fir, lodgepole pine, white birch (Betula papyrifera Marsh.) and trembling aspen (Populus tremuloides Michx.). Stands of the latter three species are common on burns and disturbed areas but they are usually replaced by white spruce and alpine fir, within 100 years, except on very dry habitats. Black spruce (Picea mariana (Mill.) BSP.) is found on the margins of lakes and bogs. Black cottonwood is common on moist, alluvial soils. The immature stand became established following fire and logging during the last 120 years.

The average height of dominant white spruce at 100 years varies
from 70 to 120 feet. Diameters between 10 and 20 inches are frequent and
may exceed 30 inches if the trees are open-grown and on good sites. Basal
area often reaches 250 square feet per acre. Mature trees, 150 to 250 years,
attain heights of 150 feet although 100 to 130 feet is more common. Diameters
of these trees are usually less than two feet but may grow to 3 feet.

VEGETATION, SOILS, TOPOGRAPHY AND CLIMATE

The forest sites, based on ground vegetation, are typical of
the Oplopanax, Disporum, Aralia-Dryopteris, Cornus-Moss site types described
by Illingworth and Arlidge (1960).

Soils in the main study area are part of the Chilako Stony Soil
Complex, derived from glacial till, and the Bednesti Silt Loam which was
derived from glacial river and lake deposits (Kelly and Farstad 1946). The
topography is level where the latter soils are found and rolling in areas
with the Chilako soils. Elevations range from 2,500 to 2,800 feet above
sea level.

The mean annual temperature between 1944 and 1961 was 38 degrees
F. with a low monthly mean temperature of 11 degrees in January and a high
of 59 degrees in July. Precipitation was lowest in April (average precipita-
tion 1.05") and highest in August (average precipitation 2.99"). Mean annual
total precipitation was 24.15" (Anon. 1962b).

METHODS

COLLECTION OF DATA

Accessible even-aged stands of predominantly white spruce,
representative of a range of ages (20-110 years) and densities (up to 270 sq.
ft./ac) were located with the aid of aerial photographs. Three hundred and

eighty spruce, having a symmetrical crown and well-formed bole were measured, each tree being the centre of a plot; diameter of the plot was equal to the height of the centre tree. Twenty trees were also measured in 140- to 240-year-old stands of mature spruce. The following data were recorded for each tree:

(1) Total height

(2) Height to the base of the live crown (distance from the ground to the average height of the lowest live branch in each quadrant)

(3) Diameter outside bark at 9 feet, 4.5 feet and 1.5 feet

(4) Diameter at breast height at 5-year intervals from the cambium to the pith.

(5) Age at breast height

(6) Crown width (average diameter of the vertical projection of the green crown)

(7) Species, d.b.h. and distance of potential competing trees.

Supplementary data:

(1) Age at 1 foot (50 trees)

(2) Height-age growth data based on stem analysis (8 trees)

OFFICE ANALYSIS

Stand density was evaluated in a separate study utilizing data from this project. Basal area and point density (Spurr 1962) were related to radial growth, per cent live crown and other variables sensitive to competition. This study, which will be reported separately, showed that basal area per acre was as closely related to radial growth and to per cent live crown as to point density which was much more difficult to measure. Analysis indicated that it was only necessary to measure the basal areas of competing trees with diameters greater than three quarters the diameter of the centre tree and within a distance equal to one fifth of the height of the centre tree. For

example, trees competing with a 100-foot tree with a diameter of 16 inches
would be greater than 12 inches in diameter and not more than 20 feet away.
Consequently, basal area per acre, rather than point density, was used to measure
competition or stand density in the present study.

The site quality of each plot was based on total height at age 100.
These estimates were obtained from site index curves using the height and
age data from the centre tree. Stem analysis of eight trees indicated that
neither the site index curves developed by the British Columbia Forest
Service (Anon., 1959) nor those constructed for southern British Columbia
(Mitchell, 1963) were suitable. However averaging both sets of curves
resulted in a very satisfactory set of site index curves.

Age at breast height was corrected to obtain total age by adding
the number of years required for trees to grow to a height of 4.5 feet
(Table I). Table I is based on height growth curves of young spruce
trees in the Prince George Forest District (Eis, 1962). The site index
corresponding to each curve was determined by comparing the number of
years required by these young spruce to grow from one foot to breast
height with similar data from 50, 70 to 110 year-old trees for which
height at age 100 (site index) could be determined accurately.

TABLE 1.   NUMBER OF YEARS REQUIRED TO REACH BREAST HEIGHT

Site index (height at age 100)	120	110	100	90	80	70	60
Years to reach breast height	9	10	11	12	14	16	18

Total height was substituted for age in the analysis to determine
if it was practical to use height, density and site index to estimate the
crown width-diameter ratio.

Crown width-diameter ratios were calculated by dividing the crown width in feet by the diameter (o.b.) at breast height in inches. Graphic analysis showed that the crown width-diameter ratio was closely related to age. However, the role of competition and site index was not obvious, making it necessary to employ statistical regression methods. The diameter-crown width ratio (D/CW) was used in place of the crown width-diameter ratio in the remainder of this study because the relationship between the D/CW ratio and age was linear and, more suitable for statistical analysis (Figures 1a, 1b).

The relationships of the quantitiative variables explained above are expressed mathematically in two models. A model is usually a number of mathematical equations which, as a group, describe certain relationships. In this paper, each model is based on one equation. In Model I, the D/CW ratio is related to stand density, age and site. Model II is similar; however, diameter is the dependent variable. The second model was developed to gain a better understanding of the interaction between stem diameter and crown width which resulted in the D/CW ratios examined in Model I. Standard least squares methods of regression and correlation analysis were used (Ezwkiel and Fox, 1959).

RESULTS

MODEL I

The proportions of the variation in the D/CW ratio accounted for by age, site and density are given in Table 2. Values refer to the square of the correlation coefficient or the coefficient of determination (r^2) expressed in per cent.

TABLE 2. PROPORTIONS OF VARIATION IN D/CW EXPLAINED BY AGE,SITE AND DENSITY

Age	69.4%	Age and site	73.6%	Age, site and density 73.6%
Site index	0.1%	Age and density	69.4%	
Density	4.8%			

Age, site index and density have been related to the D/CW ratio separately in the first column of Table 2 to determine which single variable explained the largest proportion of the variation. This variable, age, was then considered with each of the remaining two variables to determine which one accounted for the largest proportion of the variation in the D/CW ratio not explained by age. No additional variation could be explained by density. However, 4.2% (73.6 - 69.4) of the variation not already accounted for by age could be attributed to site index. This value is highly significant but not necessarily important.

It should be noted that the proportion of variation in the D/CW ratio explained by age (69.4%), site index (0.1%) and density (4.8%) are not additive unless interactions among the variables are taken into account as has been done in Table 2. The coefficients of determination (r^2) between age and site index and between age and density were .073 and .071 respectively, showing that age is reasonably independent of site and density.

Equations relating age, site index and density to the D/CW ratio are shown below with the standard error of estimate (S.E.) and proportion of the variation in the D/CW ratio explained by each equation. The least important variable has been successively eliminated and the equation recalculated.

$$(1) \quad D/CW = .010 + .00639 \text{ Age} + .00328 \text{ Site} + .00007 \text{ Density} \quad \underset{\pm .128}{\overset{\frac{SE}{(in./ft.)}}{}} \quad \underset{73.6\%}{\overset{r^2 \text{ x } 100}{}}$$

$$(2) \quad D/CW = .008 + .00644 \text{ Age} + .00332 \text{ Site} \qquad\qquad\qquad\qquad \pm .128 \quad 73.6$$

$$(3) \quad D/CW = .345 + .00602 \text{ Age} \qquad\qquad\qquad\qquad\qquad\qquad \pm .137 \quad 69.4$$

For simplicity, the intercept (.008) in the second equation can be omitted as it is unimportant. The recalculated equation is:

$$D/CW = .00645 \text{ Age} + .00338 \text{ Site} \underset{\pm .128}{\overset{SE}{}} \qquad \underset{73.6\%}{\overset{r^2 \text{ x } 100}{}}$$

This equation, representing Model I, is illustrated graphically in Figure 2. A 60-year-old tree on site 80, for example, would have a D/CW ratio of .657. A three dimensional diagram is also shown in Figure 2. Corresponding lines are numbered.

The third equation, with 95 per cent confidence bands for the slope and intercept of the regression, is shown graphically in Figure 1b.

Height was substituted for age in the above equations to determine if equally reliable equations could be developed. Height would be advantageous because it can be obtained from aerial photographs. However, it explained only 46 per cent of the variation in the D/CW ratio compared to almost 70 per cent accounted for by age.

MODEL II

Figure 1b is a two dimensional graph of Model I from which site index has been omitted for clarity. The diameter-crown width relationship by age classes (Figure 1c) is derived graphically, directly from Figure 1b. The D/CW ratio at age 60, for example, is 0.7. This value represents the slope of the 60 year age curve which must pass through the origin (Figure 1c). It was evident, when diameter was plotted over crown width by age classes (Figure 3), that the general relationships anticipated in Figure 1c apply to the basic data of this study.

Separation of the data in each age class into basal area classes (Figure 3a) and site index classes (Figure 3b) demonstrates the effect of

density and site on the D/CW ratio. For a given age class, different densities do not alter the ratio of diameter to crown width (Figure 3a) but different site indices do change the ratio as is shown in figure 3b by the fact that the curves do not have an intercept of zero.

Numerous mathematical formulae can be derived to relate crown width, age and site index to diameter. Several possible equations are shown below:

		SE (inches)	r^2 x 100
1.	D = -11.13 + .7265 CW + .08824 Age + .06166 Site	± 2.14	87.1%
2.	D = - 5.50 + .7726 CW + .07957 Age	± 2.32	84.8
3.	D = 3.51 + .00008047 (CW) (Age) (Site)	± 2.11	87.3
4.	D = 3.20 + .00761 (CW) (Age)	± 2.41	83.6
5.	D = 1.20 + .00612 (CW) (Age) + .00270 (CW) (Site) + 2.02		88.5

Equations 1 and 2 are shown for comparison but were not considered as candidates for a second model because of the unrealistic restrictions imposed by this type of equation. (Crown width would have to be assumed to be independent of age and site). Equation 5 is the most logical formula and provides the estimate of diameter with the least error (± 2.02 inches). An interaction between crown width and age and between crown width and site is expected. However, age and site are independent. Since omission of the 1.20 inch intercept does not increase the error appreciably, the recalculated equation becomes:

$$D = .00626 \ (CW)(Age) + .00328 \ (CW) \ (Site) \pm \frac{SE}{2.07} \quad \frac{r^2 \text{ x } 100}{88.0\%}$$

It was used to express Model II mathematically. The model is presented pictorially in Figure 4. In the above formula, .00626 (CW)(Age) is represented by the upper part of Model II in Figure 4 and .00328 (CW)

(Site) is contained in the second smaller part of the model. This correspondence is shown by the equation beside the model. The black thread indicates that an 80-year-old tree with a crown width of 20 feet on site 75 is expected to have a diameter of 10 + 5 = 15 inches.

DISCUSSION

The D/CW ratio is apparently more closely related to changes in age than to site index or basal area. Almost 70 per cent of the variation in the D/CW ratio is related to age (Table 2). However, this does not mean that age is necessarily the direct cause of changes in the D/CW ratio. For example, the weight and length of branches increase with age causing them to sag. This results in a reduced crown width without a corresponding decrease in the bole diameter. Consequently, the D/CW ratio would be directly related to branch weight and length but indirectly related to age.

Density unlike age, is totally unrelated to the D/CW ratio of the dominant and codominant white spruce examined in this study. This implies that stem diameter at breast height and crown width respond similarly to differences in stand density so that their relative size remains constant. Such results are expected because density regulates the length and width of the crown which in turn controls the size and development of the bole. The general relationship between average diameter at breast height and crown width by age and density classes is shown in Figure 3a. It is evident that the ratio of diameter and crown width is the same at all points on any one line, each of which includes all densities but only one particular age class. This graph demonstrates how density could cause

trees of the same age on identical sites to have different diameters and crown widths without having different D/CW ratios.

Site quality accounts for a small but highly significant proportion of the variations in the D/CW ratio not explained by age (Table 2). The correlation between site index and D/CW ratio is low because site quality, like density, causes relatively uniform changes in both stem diameter and crown width (Figure 3b). However, the curves tend to pass below the origin resulting in slightly larger D/CW ratios on the better sites. It appears that the crowns of trees on good sites may be able to support relatively larger boles than the crowns of trees on poor sites. Assmann (1961) refers to European studies of several species in which it was found that greater quantity of leaves were required on unfavorable sites to produce equal amounts of wood. This implies that site factors affect carbohydrate production of the foliage which is not fully expressed in the sheer amount of foliage. Use of a given quantity of foliage for more hours per year or greater needle efficiency on the better sites would have this effect.

The D/CW ratio of white spruce can be estimated with reasonable accuracy if only age is known, but the estimate can be improved slightly if site index is also included. Unfortunately, site index is so difficult and tedious to obtain that its usefulness may not justify the work involved. However, broad land productivity classes defined on aerial photographs could be used in place of site index since the D/CW ratio is not sensitive to site quality. Density, on the other hand, is not necessary to estimate the D/CW ratio.

Application of the results of this study in the field of forest inventory may provide an efficient method for cruising even-aged, white spruce stands if crown width, height, and possibly site quality can be determined accurately from aerial photographs. Stand age could be obtained

in the field or from management records. Diameters at breast height
could be estimated from the calculated D/CW ratio or by applying the
formula:

$$D = .00626 \text{ (CW)(Age)} + .00328 \text{ (CW) (Site)}$$

Consequently, diameters and heights obtained from photographs could be
used to estimate tree volume without intensive field sampling.

Use of the CW/D ratio as an objective measure of competition
in Douglas-fir stands was mentioned by Smith, Ker, Csizmazia (1961).
These and other management applications appear unlikely for white spruce
as stand density is not related to this ratio and age cannot be manipulated.

Future studies will evaluate crown width as a means for predicting
the growth and development of even-aged, white spruce stands. D/CW
relationships will be employed to convert predicted crown widths to
stem diameter at breast height.

SUMMARY

Diameter at breast height, crown width, height and age of 400
dominant and co-dominant white spruce trees and the basal area of competing
trees were measured in the vicinity of Prince George, British Columbia,
to evaluate the relationship between the diameter-crown width ratio (D/CW)
and age, stand density and site quality. Seventy per cent of the variation
in the D/CW ratio was explained by age alone. Site index accounted for
an additional 4 per cent. The D/CW ratio did not vary significantly with
stand density. Equations were calculated to estimate the D/CW ratio and
diameter. The equations, standard errors of estimate and coefficients of
determination (r^2) are:

	SE	r^2
D/CW = .00645 Age + .00338 Site	$\pm$ .128	0.74
D = .00626 (CW)(Age) + .00328 (CW)(Site)	$\pm$ 2.07	0.88

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FIGURE 1

Relationship of Age to Diameter and Crown Width

(a) CW/DBH vs AGE (Yrs)

(b) DBH/CW vs AGE (Yrs)

(c) DBH (Inches) vs Crown Width (Feet)

TOTAL AGE 220 200 180 160 140 120 100 80 60 40 20

Slope : 0.7

Figure 2

THE RELATIONSHIP OF THE DIAMETER-CROWN WIDTH RATIO
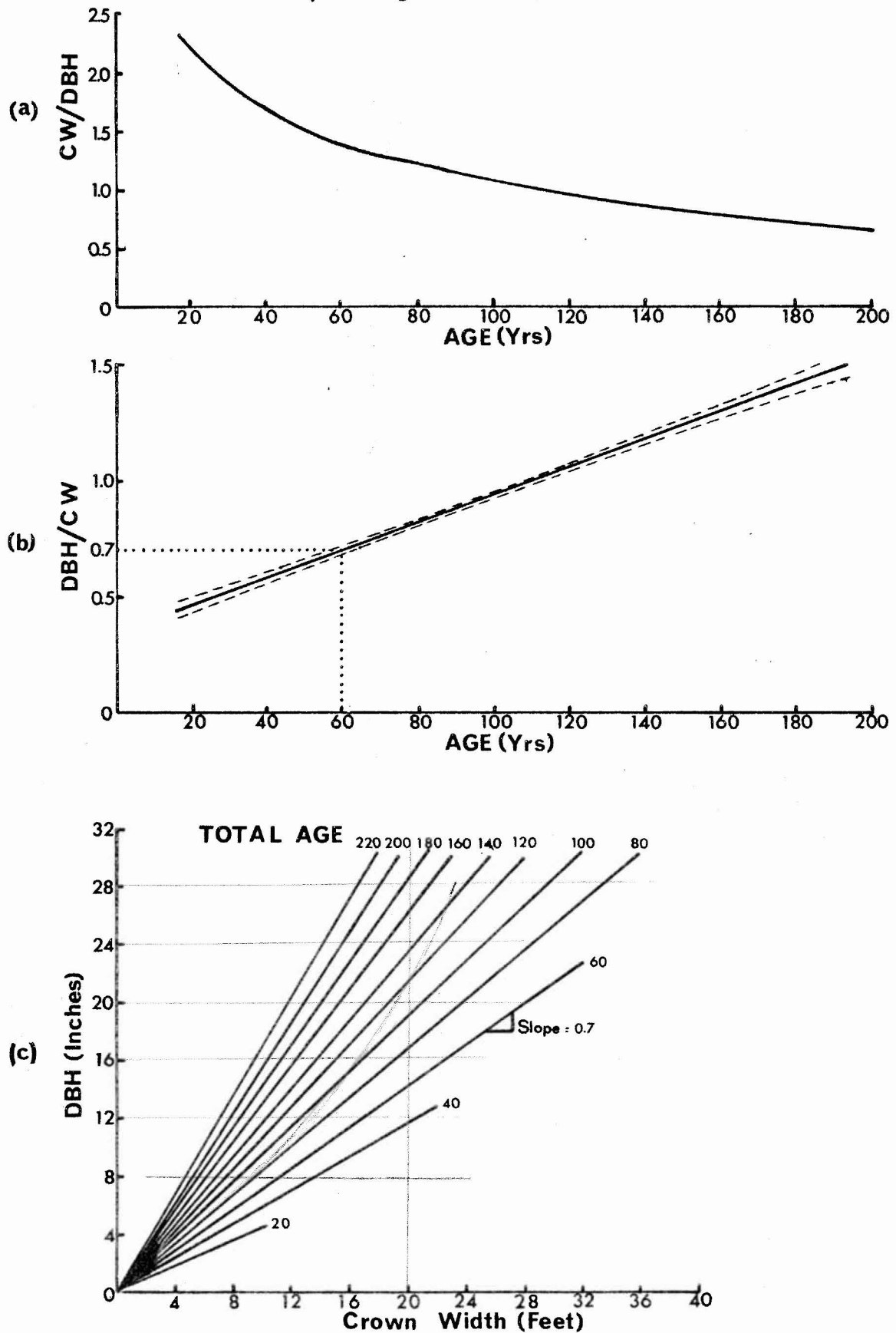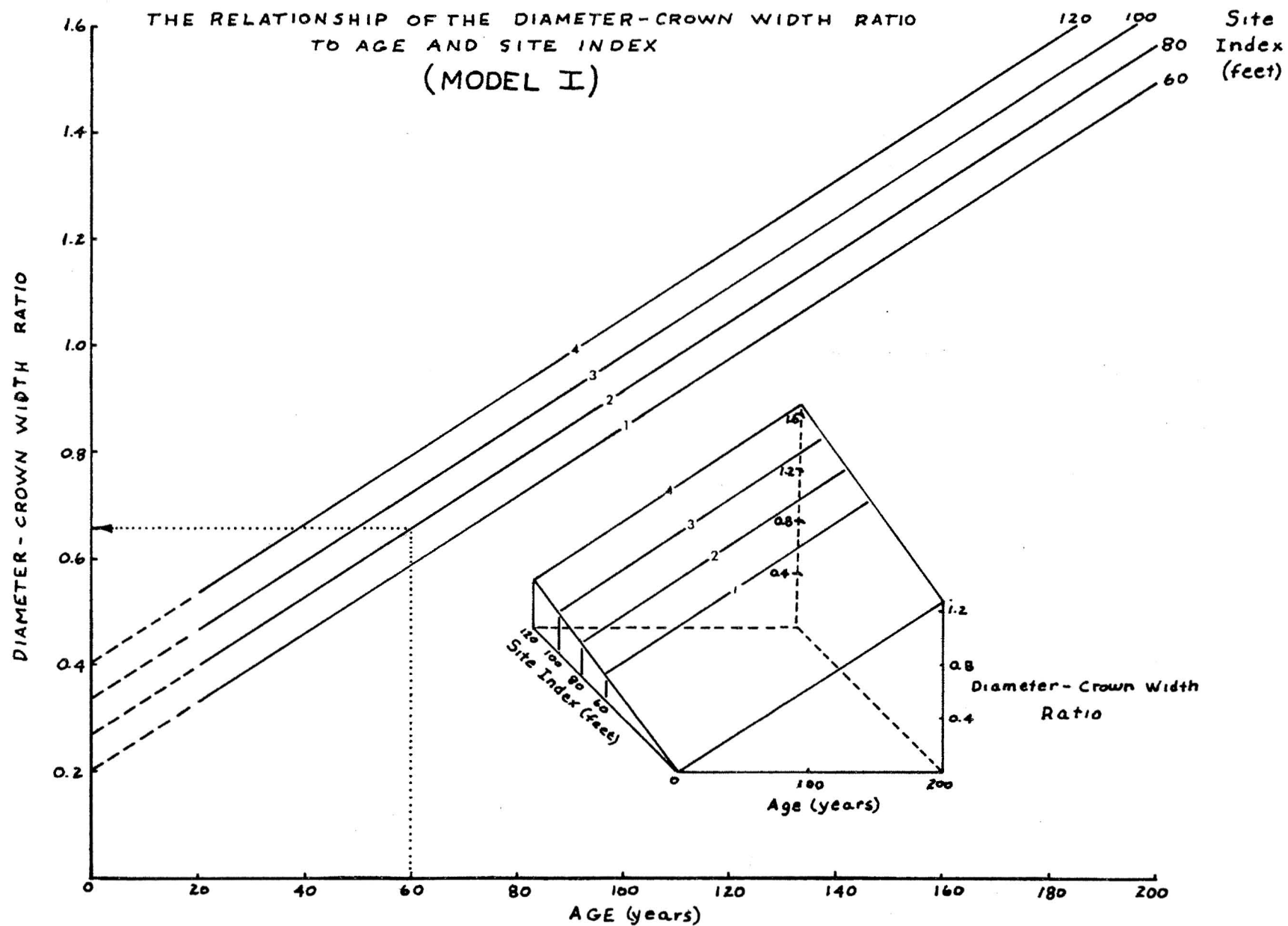TO AGE AND SITE INDEX
(MODEL I)

FIGURE 3

RELATIONSHIP of DIAMETER to CROWN WIDTH by DENSITY and SITE INDEX CLASSES