AN ANALYSIS OF SOME PHYSICAL

AND

ECONOMIC CRITERIA FOR THE

DETERMINATION OF ROTATIONS

FOR

BRITISH COLUMBIA FORESTS

by

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ABSTRACT

Committee Chairman: Dr. J.H.G. Smith

In 1968 the B.C. Forest Service provided growth and yield data in the form of nearly seven hundred volume/age curves. These were summarized quantitatively and sorted by electronic computer. Summaries were used for study of the criteria determining rotations in British Columbia. At the same time an assessment of these curves for other uses in forest land management was made.

The curve summaries illustrated the need to consider differences in region, species, or growth type, site class and utilization standards. It was shown that a direct, negative correlation exists between rotation length and site index. This was done using the physical criterion which determines the rotation age at the culmination of mean annual increment in cubic foot volume.

Because simple volume over age curves do not provide some important data such as numbers of trees per acre and average stand diameter, the study showed how several rough estimates of these would be derived theoretically. No positive conclusions could be drawn. The exercise did show, though, that the use of actual data describing stand density for fully stocked stands would benefit the forest land manager

to a remarkable degree.

The next step involved an assessment of the available financial alternatives to physical rotation determination, then compared them with approaches employed by two representative agencies in British Columbia.

The possibility of using average stand diameter as a means of approximating the financial rotation was indicated.

B.C. Forest Service volume/age curves now are useful as a tool of forest land management. They could be improved by the provision of information to define growth behaviour at full stocking, given various levels of stand density. Another conclusion was that the forest manager using the optimum accounting rate of return (single year) investment criterion and the economist using time preference criteria both have the same objective, namely the most efficient use of capital. This objective is more likely to be achieved by the manager in a series of intermediate steps. At the same time the economist's time preference may span a single rotation.

It was recommended that the B.C. Forest Service continue to develop forecasts of average stand diameter with their yield predictions as a means of introducing the financial implications of a chosen rotation.

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INTRODUCTION

The period of years required to establish and grow timber crops to a specified condition of maturity is referred to as the 'rotation' (Davis, 1966). It is used as an input for the calculation of allowable annual cuts; consequently, it controls the volume of wood harvested in British Columbia each year.

The rotation concept was first demonstrated in continental Europe during the eighteenth and nineteenth centuries through its association with long-term planning in forest management. At that time and in that area market conditions were stable, and management objectives were rigid (Johnston *et al.*, 1967). If a forest took one hundred years to achieve maximum mean annual growth (merchantable) then a rotation length of the same duration enabled the forest manager to harvest one one-hundredth of his domain each year.

Foresters of the New World have imported the rotation concept; however, the rigidity of its behaviour with respect to the control of the rate of forest harvesting in an economically dynamic environment conflicts with the economic objectives of today. To reduce this conflict it is necessary to examine existing physical and economic criteria available for use in the determination of rotations for British Columbia forests. The purpose of this study is exactly that.

The method of approach is as follows: firstly, the available physical criteria will be set out; secondly, the British Columbian position will be summarized; thirdly, analyses of the British Columbia Forest Service Volume/Age curves (V.A. curves) will be performed, then conclusions drawn; lastly, available economic alternatives will be set out and compared with physical criteria, before proceeding further with conclusions and recommendations.

PART ONE

PHYSICAL CRITERIA

CHAPTER I

PHYSICAL CRITERIA FOR ROTATION DETERMINATION

The important physical criteria are derived from the following approaches:

1. natural (point of maximum volume per acre).
2. culmination of mean annual increment (m.a.i.).

A number of alternatives exist for the classification of physical rotations. The two approaches described here summarize those choices available to planners in British Columbia. The favoured silvicultural system here includes clear-cut harvesting. Because of this the rotation criteria set out are connected for the most part with even-aged stands; although they may serve equally well in planning harvest cuts with uneven-aged forest management.

1. Natural (Point of Maximum Volume Per Acre)

The natural rotation, according to Davis (1966), is sometimes used to define the average life of stands in the forest state. As stands proceed in age beyond the vigorous, healthy stage the volume increment lessens each year. Finally the forest reaches a time when the useable volume per acre fails to increase at all. The year's volume increment on trees of merchantable size becomes offset completely by volume that is lost through decay and by mortality caused by weather, animals, and insect infestation and disease. The point at which merchantable volume culminates defines the span of the natural rotation (see Figure 1).

It is possible to confuse the rotation just described with the 'pathological' alternative. Davis (1966) referred to the latter as follows: "...more accurate to speak of limitations on the rotation imposed by pathological factors. In mixed stands, and with even-aged management particularly, the shorter-lived key species in the stand tend to control the rotation applied to the stand as a whole".

The criterion of maximum volume per acre produces the longest rotation length. It effectively defines the upper limit of the available choices. In comparison, the criterion of maximum mean annual increment is used to determine a rotation somewhat shorter.

2. Culmination of Mean Annual Increment (M.A.I.)

Johnston *et al*. (1967) stated that before wood pulping began sawlogs provided the bulk of forest revenue (in Europe) and: "...the sawing technology was itself based on the size of the

FIGURE I. A TYPICAL VOLUME/AGE CURVE SHOWING THE RELATIVE POSITIONS OF TWO ROTATIONS BASED ON SEPARATE PHYSICAL CRITERIA (AFTER CAREY, 1960)

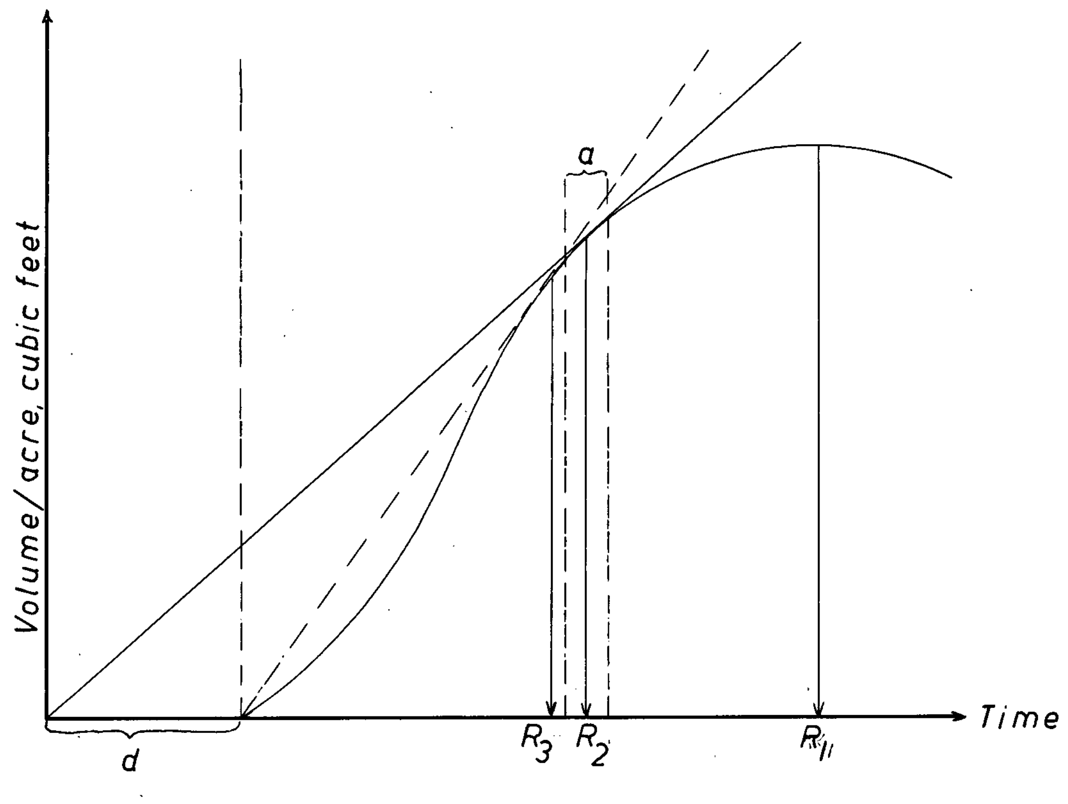
R_1 = rotation based on the culmination of m.a.i., with an allowance for regeneration delay.

R_2 = rotation based on the natural culmination of volume/acre.

a = range in years about R_2.

R_3 = accelerated rotation due to a policy of prompt reforestation after logging.

d = time saved by prompt reforestation.



tree produced on conventional, rather long rotations around the age of culmination of mean annual increment". New World foresters have inherited this criterion in the form of the culmination of m.a.i. only. Since the wood on each forest acre grows at a decreasing rate after a particular time period, the forest manager must plan to liquidate the accumulation of fibre at the position of maximum mean annual growth rate (see Figure 1). If he delays, or removes the wood too early he loses his chance of maximizing volume production over several rotations.

The position of maximum m.a.i. may have flexibility as shown by the range 'a' in Figure 1. This range of years in which the m.a.i. remains virtually unchanged is well known (Carey, 1960). The m.a.i., expressed in cubic feet, culminates sooner than the same measure expressed in board feet. On poorer sites at least, volume in the latter form takes longer to develop (Davis, 1966).

It is interesting to note that the B.C. Forest Service, through Davis Carey, forester, demonstrated the graphical derivation of rotation, cutting age and m.a.i. in the Forestry Chronicle of September, 1960. This test of the volume/age approach probably initiated the volume/age curves now used by an increasing number of foresters to determine rotations on lands of all tenures in this Province.

Carey also pointed out the fact that the tangent method of determining the time at which m.a.i. culminates is an adequate substitute for the former method which relied on the intersection of m.a.i. and p.a.i. (periodic annual increment). This latter measure is a doubtful one anyway because the remeasurements from which p.a.i. ought to be calculated are rarely taken.

The rate of growth or volume increment requires qualification before being used in rotation determination. The additional factor needed is the relevant utilization limit. Growth expressed in any of the usual measures is either considered to be 'gross' or 'net'. The former indicates that no deductions for subsequent losses from processing or natural reduction have been made. The latter describes a gross value which has been transformed through certain deductions into its net equivalent. For instance it is usual to relate this deduction to some level of utilization. If a forest manager sells his wood in log form the buyer's conversion processing will handle these logs down to specified, merchantable limit. Any wood below this limit is left on the ground in the form of tips, branches and stumps; consequently, rotations based on gross volumes culminate faster than those using net (reduced) values. Such utilization (merchantability) limits are expressed in terms of minimum top diameters inside bark and to given diameters at breast height (dbh) in inches. Specified stump heights may be included as well.

Other wood may also be left on the ground. This is the 'reject' wood which is too full of decay or too damaged to be used in manufacturing. Net volumes, then, may ignore all wood that will be left on the ground in the normal course of harvesting, or just that lost through decay. An example of this latter case is the net yield estimated from a B.C. Forest Service volume/age curve.

Having reviewed the principal physical criteria in the determination of rotations the next step is to investigate the British Columbian approach.

CHAPTER II

ROTATION DETERMINATION IN BRITISH COLUMBIA

Historically, in British Columbia, rotation lengths have been reviewed periodically to determine their validity at a particular time in the development of the Province. These reviews have been motivated usually by the receipt of new information concerning mature volumes, immature growth rates and improved land classifications. Where formal reviews are lacking the annual reports of the British Columbia Forest Service (B.C.F.S.) offer indications of official practices.

Leonard Higgs in 1911 assessed available data for the Provincial timber resource. He used information gathered by the 1910 Royal Commission on Forestry. In this report Dr. Fernow's conjecture of from thirty to fifty million acres of merchantable forest was given credence (Sloan, 1956). Higgs reviewed the effects of using rotations from fifty to one hundred and twenty years, then decided that a hundred year rotation would combine the financial benefits of larger trees and their increment of clear wood, with an adequate array of age classes in the replacement forests. A rotation of this length would also include a necessary length of time for regeneration. Connected with this proposal was the mention of a proposed forest service. One task of this body would be to apportion the entire forest into a proper number of tracts: "...carrying trees of the requisite age classes" (Higgs, 1911).

As an indication of Provincial practice in subsequent years the 1935 report of the forest branch outlined a calculation of the annual allowable cut on a proposed coastal forest reserve (Nimpkish). There were others, but this showed clearly the rotation length adopted. Given a total mature inventory (no immature age classes existed) of 10.9 billion board feet supported by an area of 399,000 acres, the allowable cut became 109 million board feet of timber each year. The rotation applied would seem to have been one hundred years (10.9 billion board feet/100 years). The time allowed to regenerate the forest, also the provision of an ordered set of age classes in the next rotation, are implicitly stated.

Mulholland (1937) used summaries of newly acquired inventory information to examine the Provincial capacity for sustained annual yield. The rotation inputs used were from one hundred to one hundred and twenty years for the coastal forests and from one hundred to one hundred and eighty years for the smaller, slower-grown trees of the Interior. These were his estimates of the time taken to grow a crop of trees based on the existing utilization standards of the time.

In a less defined manner he proposed a second rotation level in the event that smaller trees became merchantable within the next half century. This was a sixty-year growing cycle. The following extract from Mulholland's report (1937, page 56) indicates the belief behind his choices of the two rotation levels:

> "...it would be reckless to exploit the accessible forest resources without limit, on the unproved belief that the next generation will not need the products of old-growth timber and that quickly grown trees and forests now inaccessible will meet the demand. Somewhere in between, thinking always a little ahead of conditions of the day, as these conditions change, those responsible for British Columbia's forests can develop a flexible policy of forest regulation. Its success or failure will depend upon the good judgement and ability of those who develop it; upon the accuracy of their forecasts of future developments; upon the extent of their regard for the interests of futute generations in comparison with the importance they attach to the satisfaction of present desires."

The Sloan report of 1945 reiterated the use of the sixty-year cycle for average coast sites supporting Douglas Fir. This recommendation was considered valid only if industry demonstrated its ability to actually utilize material associated with this rotation. In fact, industry did not receive this chance. The forecasted depletion of old-growth Douglas Fir stocks, with a consequent shift to the logging of second growth, failed to occur.

A second Sloan report (1956) re-examined all aspects of forestry in the light of development in the intervening ten years. Then the British Columbia Forest Service published a new forest inventory (B.C.F.S., 1958). With this latest information in hand public policy was revised to incorporate an assumption of two rotations: one hundred years for coastal forests and one hundred and twenty years for Interior forests. The sixty-year cycle was held in abeyance. Insufficient data still existed to provide designated rotation lengths for differing species and sites.

Sloan, himself (1956) offered a number of guidelines to the determination of rotations:

1. Within a management area, be it public or private (industry), a number of working circles would be created according to grouping by site quality, species and end use. Each working circle would have its own working plan based on a particular rotation length. Here was envisaged a technical rotation, one would suppose, of perhaps sixty years for hemlock pulp and ninety or one hundred years for Douglas Fir sawlogs.

2. No schematic law or regulation should prevent the experienced forester from modifying existing information to suit the individual characteristics of the forest in his charge. This is especially true where existing information is inadequate. In the absence of desired site and growth data the setting of the rotation length requires testing through area-volume checks. The average rotation value in Hanzlik's formula (U.B.C. Forestry Handbook, 1959) may require some modification.

3. The designated rotation lengths should be large

enough to provide an evenly graduated series of age classes in the reforested land. At the same time they need to be short enough to prevent disastrous losses by insects and decay to the overmature timber of zero increment.

Sloan (1956), then, was able to assign two functions to rotation length: the first to serve as a divisor of the presently mature timber (old growth), the second to serve as an ingredient in the formulation of future timber supplies denoted by projected diameter (size) demands. In addition, as adequate survey information is collected on the variety of site qualities available, it will be found that a number of rotation lengths may exist within the border of a single sustained yield unit. Depending upon growth capacity the range of rotations may be expected to range from sixty to over one hundred years, as indicated by management objectives.

Since the B.C. Forest Service inventory (1958) has shown an annual decay loss in the forests of the Province of some two billion cubic feet (as compared to a current Provincial cut of 1.6 billion cubic feet annually[1]), the prime function of the rotation length must be to govern the rate of liquidation of existing old growth timber. Some replacement stands may well grow at eight times the rate of those liquidated (Paille, 1968).

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[1]Source: British Columbia Forest Service, 1967.

In 1964 the B.C. Forest Service (Young, 1966) introduced volume/age curves (V.A. curves) for various growth types and four site classes in the Province. These indicate yields and rotation ages for two levels of diameter at breast height (dbh). The rotations indicated occur at the culmination of mean annual increment (m.a.i.) as shown in Figure 2.

In May, 1968 there were 669 curves in use, some applicable to individual management units, others to inventory zones (see Figure 3). It is now the practice on public sustained yield units to determine rotation lengths for working plan calculations on the basis of indicated growth types and site classes. The result is a weighted average figure rather than the assumed substitute used formerly.[2]

In a wider sense this treatment of rotation length determination becomes a partial fulfillment of Sloan's (1956) recommendation in this area.

Volume/age curves are not static indicators of growth behaviour. As new plots are tallied and old plots retallied, new curves are produced. These replace the former curves which are discarded. This is a continuing program and is deserving

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[2]This information was provided by J. Jelinek, Forester, on the occasion of a visit by the author to the Working Plans and Inventory Division, British Columbia Forest Service, Victoria, in the summer of 1968.

of much credit to those who initiated the procedures.

To this date no attempt has been made by the B.C.F.S. to summarize volume/age curves by zone, site, predominant species, and many other variables. Such information could provide useful guides in regional and Provincial planning. The relationship of site index to rotation length and the effect of utilization limits on rotation length are two more questions which require factual explanations. Volume/age curves might also provide some bases for investigating degrees of stocking, average stand diameters, numbers of trees per acre and stand density for the species types chosen.

Because they represent actual stand averages the volume/age curves can provide empirical yield values only. They can not represent expected or standard quantities which ought to be associated with more intensive management practices.

CHAPTER III

AN ANALYSIS OF VOLUME/AGE CURVES

1. Introduction

The basic data for volume/age curves developed by the Forest Service originated from more than 53,334 plots, some temporary and others permanent (B.C. Forest Service, 1966). The analysis attempted here makes use of 663[3] curves compiled from these basic data. They are averages of volumes per acre plotted within grouped ages or age classes.

Volume/age curves represent seven inventory zones, sixteen growth types (determined from the predominant species in a particular stand) and four site classes. Because volumes are net for decay only, falling breakage and other losses due to the production processes are not deducted. In this study volumes per acre are compiled to the nearest one hundred cubic feet (C cf). Individual tree volumes and m.a.i. are expressed in cubic feet (cf).

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[3]In May (1968) 669 curves were considered to reflect the latest sampling information out of a total of some 900 curves produced; however volume/age curve numbers 338, 339, 340, 438, 580, and 824 are not included in this study. They were not requested in time for the commencement of data processing.

Each volume/age curve in fact represents two volume/age relationships (see Figure 2). The first is applicable to close utilization limits and the second is applicable to intermediate utilization limits (approximating a current level of utilization). A third utilization level is also available but it has specific application only to peeler log production in certain areas of the Interior. The curves are described further in the next section under data inputs and processing.

As a means of performing the analysis, information from the curves was entered on coding sheets. It was then transferred to punch cards for processing on an I.B.M. 7044 digital computer. The sheets and cards are filed at the Faculty of Forestry, University of British Columbia.

2. Data Inputs and Processing

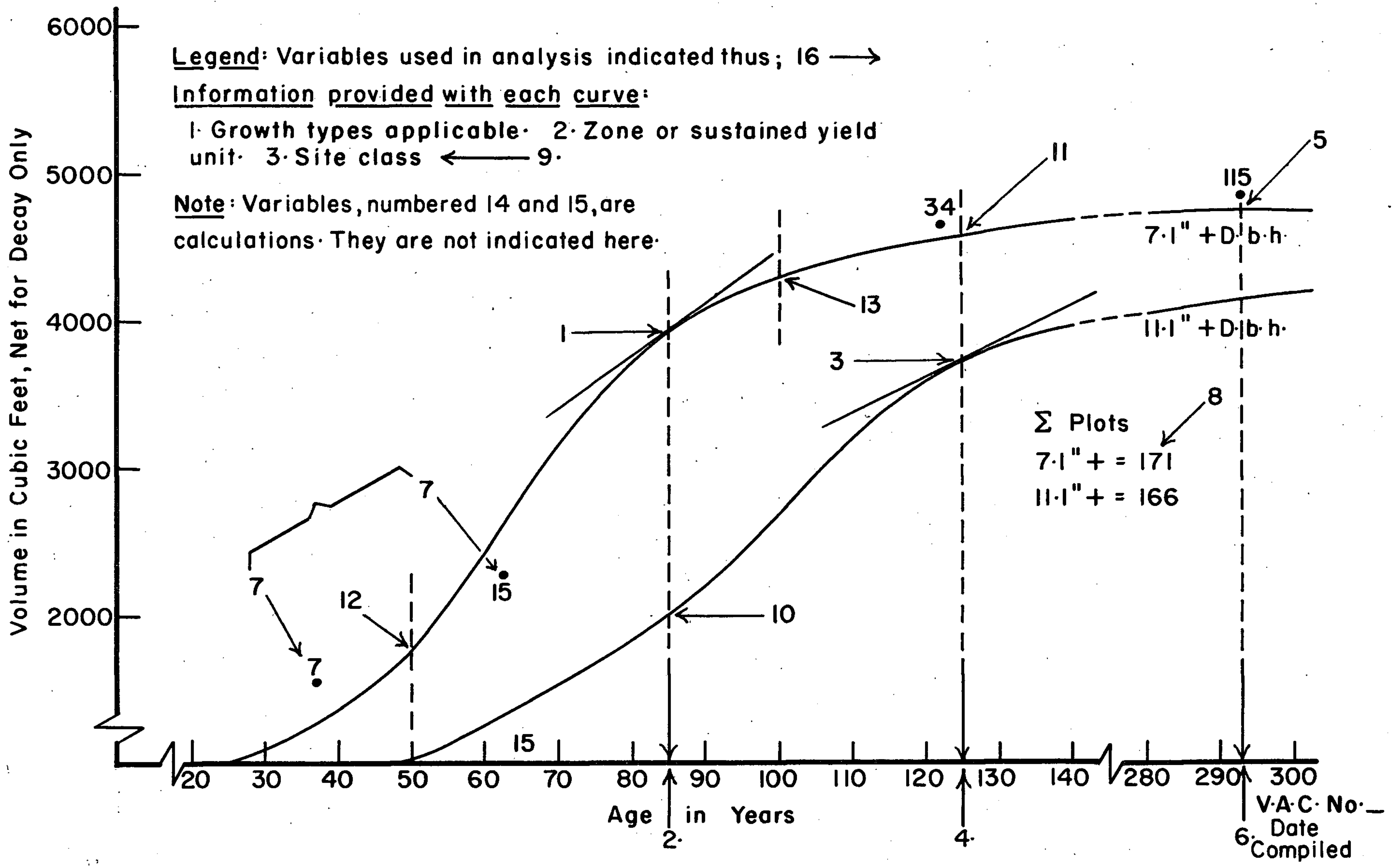
Figure 2 depicts a volume/age curve. It illustrates fifteen variables used for data summaries produced by program 1. They are described as follows:

X_1 = YA, the yield in C cf per acre at RA years;

X_2 = RA, the rotation age in years for volumes in trees 7.1 inches dbh and larger, at 9.1 inches dbh and larger respectively;

X_3 = YB, the yield in C cf per acre at RB years;

Figure 2. Diagram of typical V. A. curve used in the analysis.



X_4 = RB, the rotation age in years for volumes in trees 11.1 inches dbh and larger or 13.1 inches dbh and larger respectively;

X_5 = YC, the yield in C cf per acre at RC years;

X_6 = RC, the age at which stand volume, within the assigned limits, culminates; in this analysis either at 7.1 inches dbh and larger or 9.1 inches dbh and larger;

X_7 = the number of sample plots used in constructing the curve for the portion from zero to R years;

X_8 The total number of sample plots used to construct the curve for 7.1 inches dbh and larger or 9.1 inches dbh and larger;

X_9 = average site index as determined from Table 1;

X_{10} = YA' (YAP), at RA: the yield component in C cf per acre attributable to the larger diameters limit indicated;

X_{11} = YB' (YBP) at RB: the yield component in C cf per acre attributable to the smaller diameter limit indicated;

X_{12} = VP50, volumes in C cf per acre at age 50 years;

X_{13} = VP100, volume in C cf per acre at age 100 years;

X_{14} = M.a.i., mean annual increment in cubic feet per acre calculated from YA/RA;

X_{15} = GRPT, growth rate in per cent using VP50 as base year; it is calculated in simple interest as follows: (VP100 - VP50)/(50 years)(VP50) /100; in effect this is a simple interest rate expressing periodic annual increment from 50 to 100 years. It often represents the period of most rapid merchantable growth and it provides a common age reference for comparison of all curves.

These, then, were the variables measured for the study. It can be seen from Figure 2 that lines originating at the zero point at the junction of the x and y axes, and drawn tangentially to the respective volume/age curves, indicated the rotation ages required. Once these data were punched onto cards they could be sorted into a number of different summaries.

The categories used in sorting will be described next. They are as follows:

A. zone

B. growth type

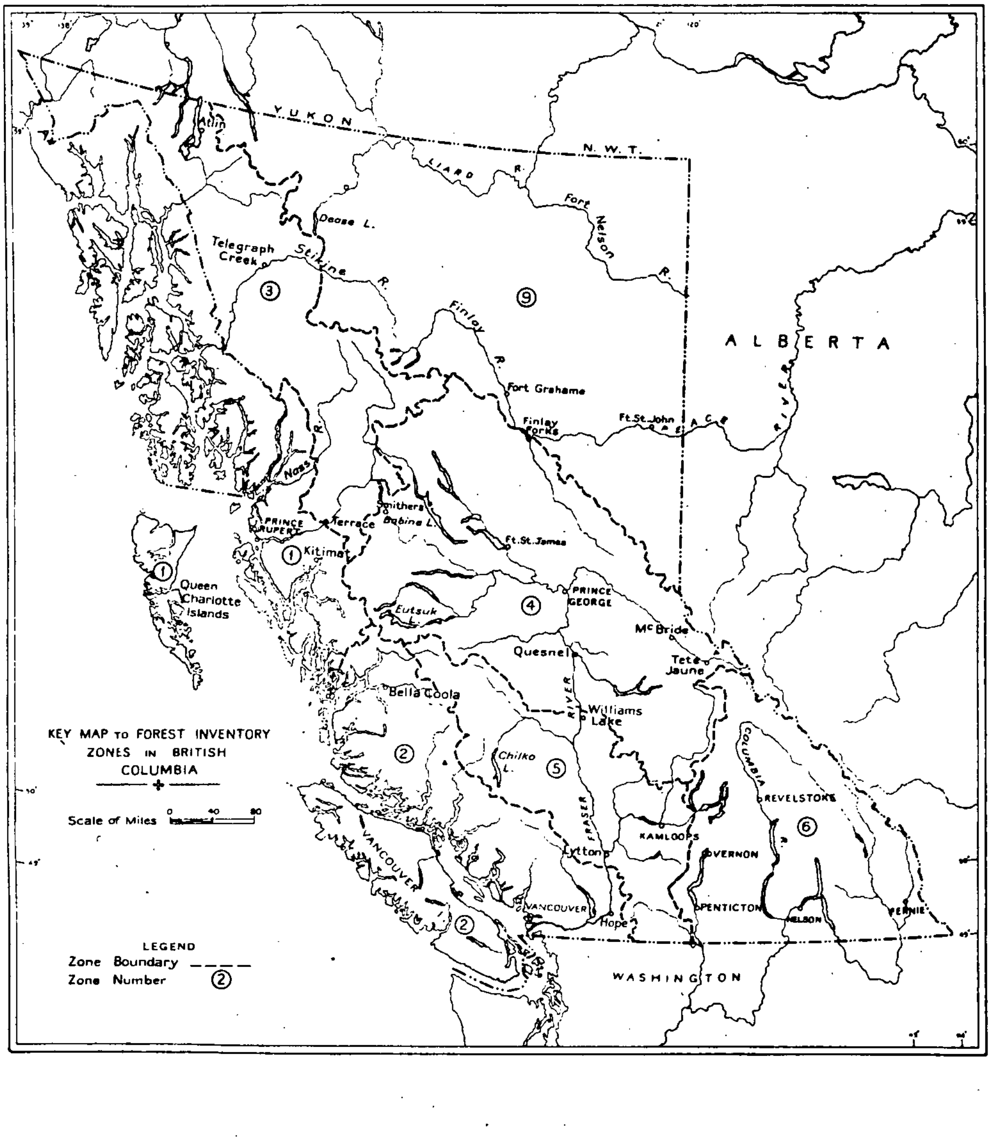
C. site class

D. utilization limit (U. limit).

A. Zone - Figure 3 illustrates seven inventory zones (1, 2, 3, 4, 5, 6, 9) set aside in the Province. Numbers 0 and 7 were used for special zone summaries in the analysis. Their

FIGURE 3

KEY MAP TO FOREST INVENTORY ZONES IN BRITISH COLUMBIA (FLIGG, 1960)



description follows:

0 - data common to both zones 1 and 2

1 - North Coast

2 - South Coast

3 - Northwest Interior

4 - North Central Interior

5 - South Central Interior

6 - Southeast Interior

7 - data common to all zones

8 - not used in the analysis

9 - Northeast Interior

B. Growth type - Volume/age curves are assigned to specific growth types (16 in number). These are defined in Table II. In practice it was desirable to sort the curves by grouped growth types (species predominant). In coding the curves it was found often that the species description was common to two or more types. Table 1 indicates those growth types common to a particular predominant species. In addition fewer mistakes were made in coding to predominant species than to individual growth types. This also applied to the coding of median site indices.

C. Site class - Table I indicates site index values applicable to each of the four site classes: good, medium,

TABLE I

SITE CLASSIFICATION*

Species Predominant	Growth Types	Median Site Indices** 1-Good	2-Med.	3-Poor	4-Low
Coast F	1,2	160	120	80	40
Coast H,B,C,S	5,6,7,8,9,10,11	150	110	70	40
Interior F,L	1,2,3,4	100	80	65	30
Interior C,H	5,6,7	110	90	60	30
Interior S,B,Py,	8,9,10,11,3	96	75	53	30
Pw.	1,4	130	110	70	30
Pl.	12,13,14	90	70	50	30
Cot.	15,16	140	100	60	30
D,A,B	15,16	130	90	65	30

*Source: Fligg, D.M. (1960)

**Average height in feet of dominants and codominants at 100 years. The median site index is the midpoint of a range and approximates the mean.

poor and low. Officers of the Forest Service have indicated that data for class 4 were not readily available for use in constructing volume/age curves; therefore, they were forced by circumstances to take class 3 curves, then estimate class 4 values by subtracting a fixed percentage of the known yield values. This accounts for the lack of variability in site index values for site class 4.

Median site indices were used in the coding of curves because they approximated the midpoint of the range of site indices within a particular site class. This latter point of course represents the mean in a normally distributed population.

D. Utilization limits (U. Limits) - Again Figure 2 may be used to indicate the properties of a volume/age curve. The utilization limits shown are lower limits of 7.1 inches dbh for close utilization and 11.1 inches dbh for intermediate utilization. They indicate RA and RB rotation lengths accordingly. A description of utilization limit codes follows:

U. limit 1: used for all growth types in coastal zones 1 and 2. The lower limits are 9.1 inches dbh and 13.1 inches dbh, corresponding to close and intermediate utilization.

U. limit 2: used for some high elevation hemlock - true fir types in zones 1 and 2, and

TABLE II GROWTH TYPES (FLIGG, 1960)
(16 Combinations of the 42 Inventory Type Groups)

GROWTH TYPES	INVENTORY TYPE GROUPS	
	CODE	NAME
1	1	F
	5	FP1 - Zones 1 and 2 only.
	8	F Deciduous - Zones 1 and 2 only.
	27	Pw - Zones 1 and 2 only.
2	2	FC and FCy
	3	FH
	4	FS
3	5	FP1 - Interior Zones only.
	6	FPy
	8	F Deciduous - Interior Zones only.
	32	Py
4	7	FL
	27	Pw - Interior only.
	33	LF
	34	L
5	9	C
	10	CF
	11	CH
6	12	H (and HP1)
	17	H Deciduous
7	13	HF
	14	HC
	15	HB
	16	HS
8	18	B
	19	BH
	20	BS
9	21	S
10	22	SF
	23	SH (and SC)
	24	SB
11	25	SP1
	26	S Deciduous
12	28	P1
13	29	P1F
	30	P1S (and P1B)
14	31	P1 Deciduous
15	35	Cot Coniferous
	37	D Coniferous
	41	A Coniferous
16	36	Cot Deciduous
	38	D Deciduous
	39	Mb
	40	Bi
	42	A Deciduous

also for all other zones. The lower limits are 7.1 inches dbh and 11.1 inches dbh, corresponding to close and intermediate utilization.

U. limit 3: used for special calculations of peeler log utilization in zone 6. The limit is one only, 9.1 inches dbh. Seven curves in this zone are coded this way.

Appendix I contains summaries of certain variables by growth type for 628 volume/age curves. They do not include data coded U. limit 3, or for zones 0 and 7. The values of variables assigned to these curves are listed in Appendix II. It should also be mentioned that this latter Appendix contains curve data from interior zones which are coded U. limit 1, and from Coast zones coded U. limit 2. They were separated to reduce variation in the data and simplify their interpretation.

With all variable values entered onto punch cards the first program (program 1) was developed to provide the mean ($\overline{X}$), Standard Deviation (SD) and number of curves in a particular sort (N). Then sorts were made according to:

zone

grouped growth type (species predominant)

site index

U. limit

The three variables chosen were RA, VP50, and VP100. For the purpose of the stated objective they would indicate zonal and Provincial estimates in the form of averages. Because of this the application of summary data in this form to a local zrea may be misleading.

The matter of averages raises another point. It will be noticed that the data summaries for program 1 make use of the standard error of the mean rather than the Standard Deviation. This was done to indicate how well each mean was defined from the data provided. That this measure is appropriate may be judged by comparing the number of observations in a sort to the size of the standard error calculated. It is not to be forgotten that the variable means, themselves, are the products of sample means of broad age classes, originating as plot averages from the basic data.

It should be noted also that the estimates produced are not weighted by area or volume in every case. The B.C. Forest Service inventory (1958) provided acreages and volumes by zones and species groups. These were used as weighting devices to obtain estimates of some Provincial averages. Where this information was not valid, as in the case of the calculation of an average Provincial site index for instance, the Provincial estimates were obtained by weighting the individual means by their respective sample sizes.

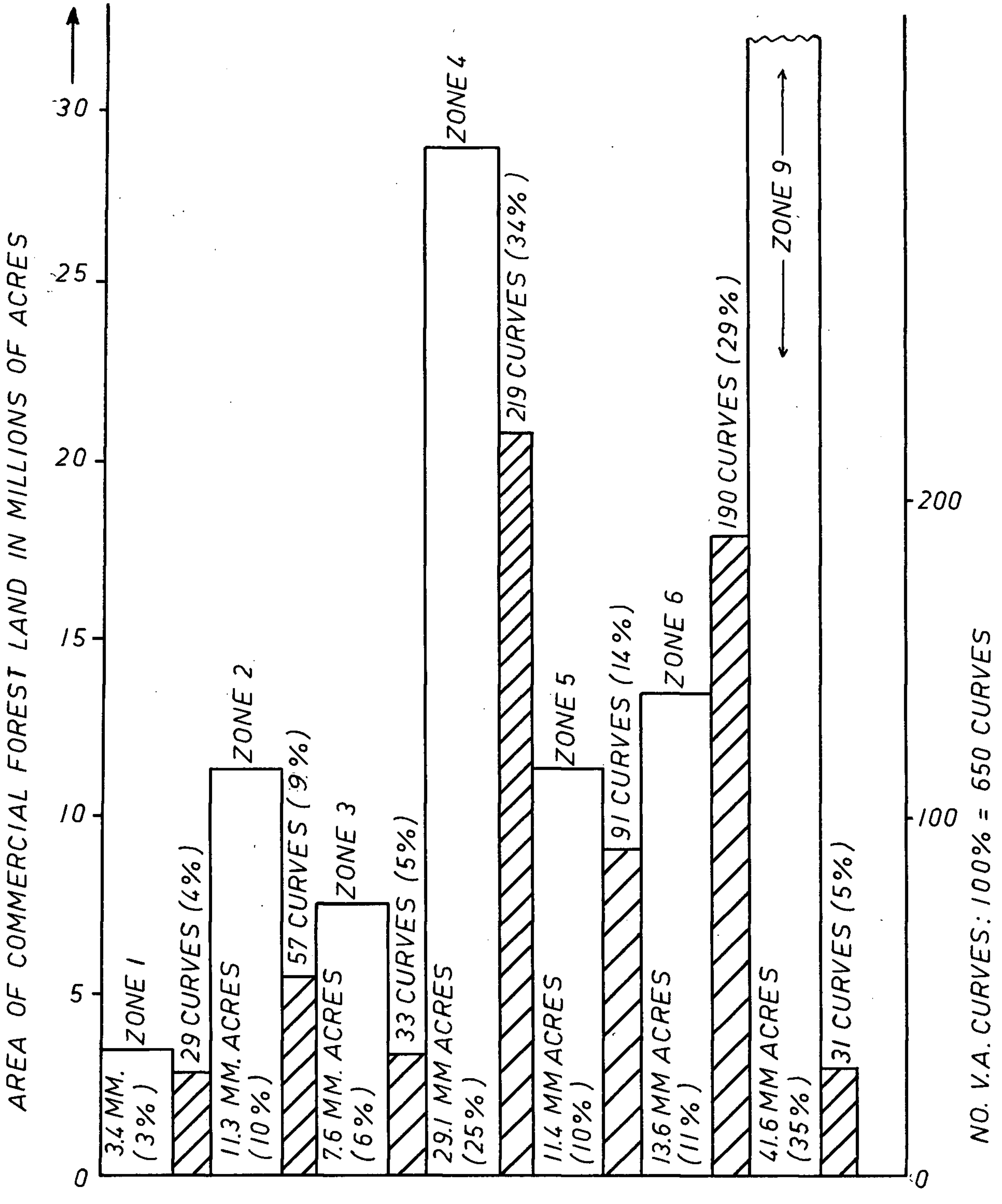
On the face of it this is a serious charge against the outcome of the analysis. But it will be shown that other estimates of the same kind, based on weighted values, agree well with some results obtained here. Criticism of the short comings of this work may be valid only if available data were not utilized to strengthen the results; however, from this study some idea of the nature of additional data has been determined. Future estimates of rotation, then, may be determined more realistically. The results of the first program are summarized forthwith:

3. Data Summaries - Program 1[4]

A. Distribution of curves - Figure 4 indicates the quantity of commercial forest land for each inventory zone as compared to the number of applicable volume/age curves. This serves merely as a guide to those areas where sampling is insufficient. It is possible to have many more acres of the same age class and site class in an Interior zone (zone 4 for instance), than one may find in a Coastal zone. From this viewpoint alone Figure 4 fails as an absolute indicator of need for further plot establishment. Specifically, though, zone 9 with 35 percent of the area and 5 percent of the applicable

[4]A standard regression program.

FIGURE 4. Comparisons of area of commercial forest land with distribution of 650 V.A. Curves, in British Columbia. (Area basis, B.C. Forest Service, 1958)



curves deserves attention. In contrast, zone 6 (11 percent of the area) yields are determined by 190 curves, 29 percent of the total. It is interesting to note that this latter case must be a direct reflection of the many commercial tree species growing in this zone. As a result, the coefficient of variations for a particular variable can only be reduced by more intensive sampling.

Having compared the distribution of volume/age curves to zone acreages, it is now possible to consider Figure 5. Here, 663 volume/age curves are compared to the areas of predominant species as determined in the Forest Service inventory (1958). Is there anything noteworthy in this instance? Perhaps - Lodgepole Pine, Western Hemlock and Douglas Fir types seem to be sufficiently sampled, at least at the Provincial level. There is still the chance that zone-by-zone comparisons may prove otherwise. Tests of significance later in the study indicate this.

B. Zone - This summary is found in Table III. Excluding the artificial zone data (0 and 7) it is seen that $\overline{XRA}$ ranges from 92 years to 107 years, and that $\overline{XVP100}$ reaches from 23 to 60 C cf per acre. A Provincial estimate for the determination of a rotation (RA) of 100 years is reasonable within the context of sawlog utilization. The equivalent yield of 36 C cf per acre at 100 years is a useful figure for

FIGURE 5: Comparisons of areas of predominant species types with Distribution of 663 VA Curves (Area basis, B.C. Forest Service 1958)

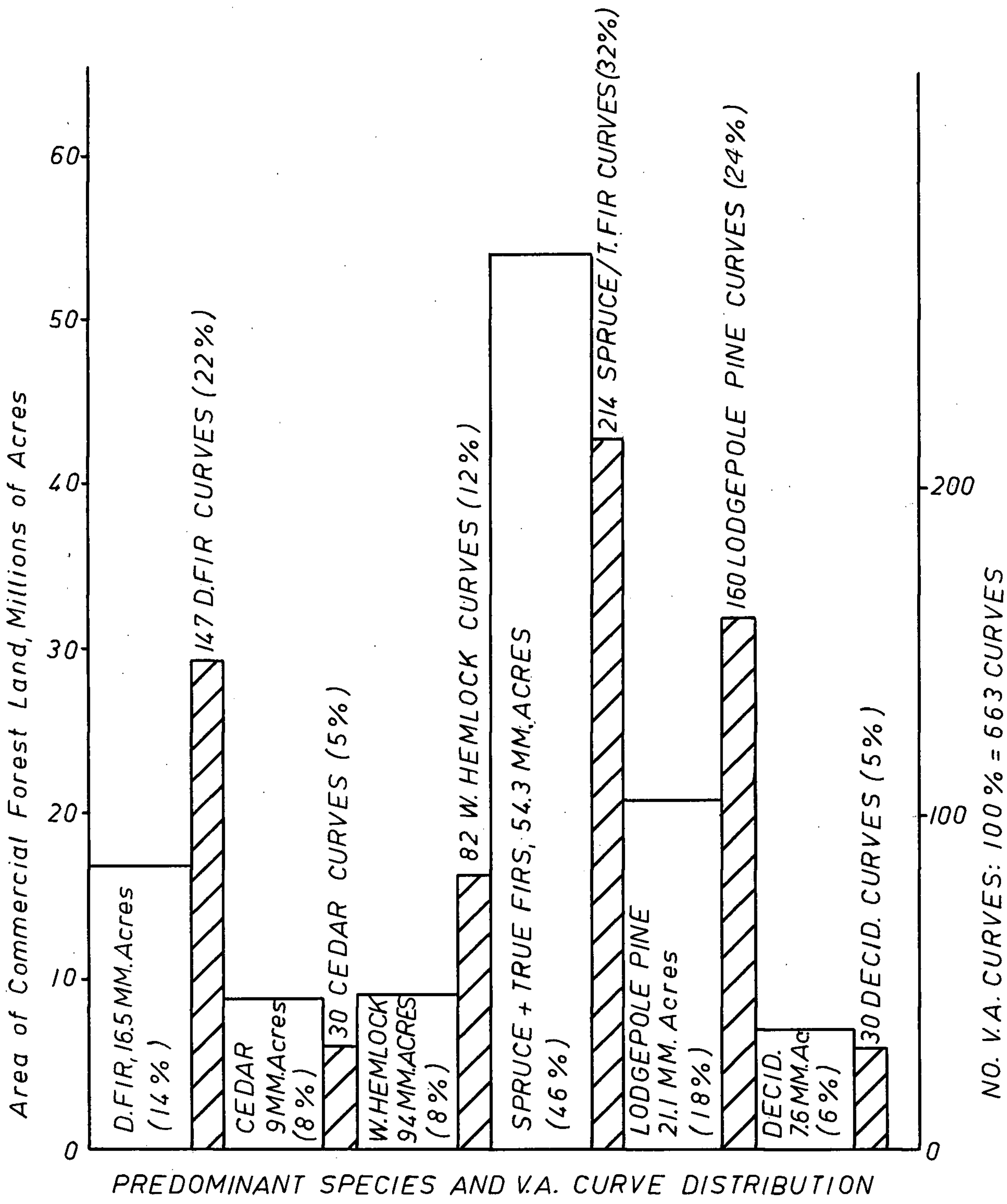


TABLE III SUMMARY OF VARIABLES RA, VP50 and VP100 BY INVENTORY ZONES

ZONE *	NO. CURVES	$\bar{X}$RA $\pm$ $S_{\bar{x}}$ YEARS	$\bar{X}$VP50 $\pm$ $S_{\bar{x}}$ Ccf/Acre	$\bar{X}$VP100 $\pm$ $S_{\bar{x}}$ Ccf/Acre
1	29	92 ± 5	27 ± 3	60 ± 5½
2	57	98 ± 5	26 ± 2½	60 ± 4½
3	33	124 ± 4	14 ± 1½	38 ± 3½
4	219	96 ±	12 ± ½	33 ± 1
5	91	104 ± 3	8 ± ½	26 ± 1½
6	190	103 ± 2	11 ± ½	31 ± 1
9	31	107 ± 4	7 ± 1	23 ± 2½
Province	650	100 ± 3	13 ± 2	36 ± 2 **

* In this summary the Provincial estimates were obtained by weighting individual values of RA, VP50 and VP100 by zone areas found in Figure 3.

** By excluding U. limits not normally used in a particular zone, eg. the use of U. limit 2 in zone 1, $\bar{X}$VP100 was found to be 5 per cent less than shown in table III those engaged in planning at the Provincial level. One should not forget that this estimate would change with intensified forest management at some future time.

C. Grouped growth type (Species Predominant) - Table IV incorporates 663 curves to provide estimates of RA, VP50 and VP100 for several predominant species. A number of facts emerge in this table. As expected the shortest $\bar{X}$RA is provided by deciduous species, 70 years. Secondly, by grouping the volume/age curves by species, the measures of dispersion from class means are reduced. Thirdly, silvicultural considerations become apparent. Western Hemlock shows an indicated rotation of 110 years, as opposed to a value for Douglas Fir of 100 years. The comparison of VP100 for the two species types indicates that Hemlock yields 48 C cf per acre at 100 years, as opposed to a figure of 33 C cf per acre for Douglas Fir.

Much of what is shown here is 'known' already; however, it is suggested that this summary, perhaps, has altered the determination of some of these differences through the realm of opinion and past experience to a means of decision-making based on facts, on a regional and Provincial basis at any rate.

D. Median site index - Table V indicates a Provincial site index of 76 feet at 100 years. This is remarkably close to Smith's estimate of 75 (Smith, 1965). Plotting the values

TABLE IV SUMMARY OF VARIABLES RA, VP50 and VP100 BY SPECIES PREDOMINANT (GROUPED GROWTH TYPE)

GROUPED GR. TYPES	PREDOM. SPECIES	$\bar{X}RA \pm S\bar{x}$ YEARS	$\bar{X}VP50 \pm S\bar{x}$ Ccf/Acre	$\bar{X}VP100 \pm S\bar{x}$ Ccf/Acre	NO. CURVES
1,2,3,4,	D. Fir	100 ± 2	13 ± 3½	33 ± 2	147
5	Cedar **	111 ± 6	17 ± 2½	46 ± 4½	30
6,7	Hemlock **	110 ± 3	19 ± 2	48 ± 3	82
8	Tr. Firs	100 ± 3	12 ± 1	35 ± 2	86
9,10,11	Spruce **	103 ± 2	12 ± 1	35 ± 2	128
12,13,14	L. Pine	96 ± 1	11 ± ½	32 ± 1	160
15,16	Decid.	70 ± 5	14 ± 2½	27 ± 4	30
PROVINCE	ALL SP.	100 ± 2	13 ± 2	36 ± 2	663*

* The Provincial estimates are weighted by the number of curves per type. The use of area as a weighting device resulted in virtually the same figures.

** No differentiation between species. For species description see the 1957 B.C. Forest Service inventory (B.C.F.S., 1958).

TABLE V SUMMARY OF VARIABLES RA, VP50 and VP100 BY MEDIAN SITE INDICES. *

MEDIAN SITE INDEX -ALL SPECIES	No. CURVES	$\bar{X}$RA ± S$\bar{x}$ YEARS	$\bar{X}$VP50 ± S$\bar{x}$ Ccf/Acre	$\bar{X}$VP100 ± S$\bar{x}$ Ccf/Acre
30	48	133 ± 4	2 ± ½	6 ± ½
40	14	150 ± 4	4 ± ½	15 ± 1
50	30	108 ± 2	3 ± ½	16 ± ½
53	59	118 ± 3	4 ± ½	20 ± 1
60	25	113 ± 8	10 ± 1½	29 ± 1½
65	44	106 ± 4	5 ± ½	18 ± 1
70	79	100 ± 2	11 ± ½	33 ± 1½
75	65	94 ± 2	12 ± ½	36 ± 1½
80	52	98 ± 3	11 ± ½	31 ± 1
90	89	92 ± 2	16 ± ½	44 ± 1
96	64	79 ± 2	22 ± 1	52 ± 2
100	38	79 ± 4	20 ± 1	46 ± 1½
110	38	90 ± 3	28 ± 1½	66 ± 2½
120	5	87 ± 14	36 ± 7½	79 ± 6½
140	2	40 ± 5	49 ± ½	79 ± ½
150	8	69 ± 4	56 ± 4	108 ± 5½
160	3	65 ± 5	67 ± 3½	131 ± 3½
76	663	100 YR ± 1	13 Ccf ± 0 Ccf	36 Ccf ± 0 Ccf

* Provincial estimates obtained by weighting with numbers of curves per class. Discrepancies in comparison of Provincial figures with those in other tables are the results of rounding off.

for $\bar{X}$RA indicates a straight-line relationship between rotation age and site index. Again, using Table V data, if one refers to site index values as X values and RA values as Y values, the coefficient of correlation (Freese, 1967) for the relationship is: $r = -0.8937$. The equation for the line tested becomes: $Y = 148.38 - 0.6054X$

This correlation between site index and RA values for combined species leads to speculation that indicated rotations for sustained yield units can be found from such a line directly. If further work is done to provide R/site index lines for each predominant species, correlation coefficients may be improved further. With this approach there is a probability that classification of lands by site index will overcome any regional deficiencies in sampling. The forest manager who cannot rationalize the growth behaviour of his stands will be able to circumvent generations of sampling to determine the culmination of m.a.i. It is an approach worth testing at the University Forest, Haney, British Columbia.

E. Utilization limit (U. Limit) - Table VI indicates that a merchantable lower limit of 9.1 inches dbh on the Coast together with the Interior equivalent of 7.1 inches dbh have nearly the same RA values. Again, the Provincial RA value of 100 years is demonstrated.

It is to be noted that the volume productivity for Coast and Interior sites at 100 years diverge, the Interior sites being only 56 percent of the Coast.

TABLE VI

SUMMARY OF VARIABLES RA, VP50 AND VP100

BY UTILIZATION LIMIT

Utilization Limit	Number of Observations	$\bar{X}RA \pm S\bar{x}$ Years	$\bar{X}VP50 \pm S\bar{x}$ C cf	$\bar{X}VP100 \pm S\bar{x}$ C cf
9.1" + 1	91	99 ± 4	24 ± 2	57 ± 3½
7.1" + 2	564	100 ± 1	12 ± ½	32 ± ½
9.1" + 3	8	118 ± 15	7 ± 2½	28 ± 4½

4. Tests of the Significance of the Differences Between Means

The data from Table III (zone summary) were used to test the significance of difference between two means for $\bar{X}$RA and $\bar{X}$VP100. The method followed was that for unpaired plots (Freese, 1967). Tables VII and VIII show the results of this test. From Table VII it is seen that zone 4 RA differs significantly from those of zones 5, 6 and 9; however, the smallest $\bar{X}$RA is 92 years for zone 1. This mean, when compared to zone 9 $\bar{X}$RA, is significantly different at the 5 percent level.

The interaction of the number of curves for each zone, together with the pooled variance for each group of curves, control the 't' value. These inputs are not shown in either table.

In the case of Table VIII data, zones 1, 2, 3, 4 and 6 may be grouped for $\bar{X}$VP100. Zones 5 and 9, on the other hand, demonstrate that the $\bar{X}$VP100 values involved are significantly different from the first grouping obtained.

Summaries of the other variables described ($\bar{X}$YC, $\bar{X}$RC, for instance) are reserved for Chapter IV.

5. Discussion and Conclusions

Because the summaries presented in this Chapter are drawn from data containing wide ranges of values, their application in the form of averages must be considered against their standard deviations. Without refinement, the use of the summary figures, to obtain m.a.i. for instance, for the calculation of an allowable cut on a local forest property may cause the making of wrong decisions. Because of the wide range of the data summarized, a local calculation of allowable cut would be made using m.a.i. values obtained from a specific volume/age curve representing the required species mixture and site class.

Preliminary conclusions from the data summaries obtained indicate the following:

1. Zone 9 sample plots may be too few in number for the

TABLE VII TEST OF THE SIGNIFICANCE OF DIFFERENCE BETWEEN TWO MEANS, APPLIED TO $\bar{X}$ RA FOR EACH ZONE, AT THE 5 PER CENT CONFIDENCE LEVEL. *

MEANS TESTED	't' VALUE	REMARKS
Zone 1 vs. Zone 2	- 0.7904	not significantly different
" " 3	- 1.8927	not significantly different
" " 4	- 0.9643	not significantly different
" " 5	- 2.3512	significantly different
" " 6	- 1.8439	not significantly different
" " 9	- 2.4241	significantly different
Zone 2 vs. Zone 3	- 0.2696	significantly different
" " 4	0.5530	not significantly different
" " 5	- 1.2324	not significantly different
" " 6	- 1.0405	not significantly different
" " 9	- 1.2677	not significantly different
Zone 3 vs. Zone 4	2.0795	significantly different
" " 5	0	not significantly different
" " 6	0.1797	not significantly different
" " 9	0.5342	not significantly different
Zone 4 vs. Zone 5	- 3.0446	significantly different
" " 6	- 2.7752	significantly different
" " 9	- 2.8210	significantly different
Zone 5 vs. Zone 6	0.2776	not significantly different
" " 9	- 0.6366	not significantly different
Zone 6 vs. Zone 9	- 0.7042	not significantly different

* Data Source: TABLE III

TABLE VIII TEST OF THE SIGNIFICANCE OF DIFFERENCE BETWEEN TWO MEANS APPLIED TO $\bar{X}$ VP100 FOR EACH ZONE, AT THE 5% CONFIDENCE INTERVAL. *

MEANS TESTED	't' VALUE	REMARKS
Zone 1 vs. Zone 2	0	not significantly different
Zone 2 vs. Zone 3	0.3520	not significantly different
" " 4	0.9304	not significantly different
" " 5	8.5322	significantly different
" " 6	9.4842	significantly different
" " 9	5.8871	significantly different
Zone 3 vs. Zone 4	1.8161	not significantly different
" " 5	3.6927	significantly different
" " 6	2.4580	significantly different
" " 9	3.5074	significantly different
Zone 4 vs. Zone 5	3.9279	significantly different
" " 6	1.4201	not significantly different
" " 9	3.6766	significantly different
Zone 5 vs. Zone 6	2.6968	significantly different
" " 9	0.9672	not significantly different
Zone 6 vs. zone 9	2.8514	significantly different

* Data Source: TABLE III

large size of the area; although, this may prove to be sufficient in view of the fewer sites and species mixtures;

2. The Provincial rotation age, based on the culmination of m.a.i. (close utilization standard) is estimated to be one hundred years;

3. Utilization limits of 7.1 inches dbh and 9.1 inches dbh exhibit virtually the same rotation length;

4. Using the 't' test the individual RA values for zones 1 to 6 inclusive may be grouped;

5. Zone 4 has a shorter average rotation length than zones 1 or 2 because of its greater proportion of Lodgepole pine.

6. Rotation lengths vary with the grouped growth type or species predominant:

Douglas Fir	100 years
Cedar (all species)	111 years
Hemlock (all species)	110 years
True firs	100 years
Spruce (all species)	103 years
Lodgepole Pine	96 years
Deciduous	70 years

7. Site index and rotation ages of stands are negatively correlated (r: -0.8947);

8. In order of productivity, yields, to close

utilization standards at 100 years for the predominant species, are as follows:

Hemlock (all species)	48 C cf/acre
Cedar (all species)	46 C cf/acre
Spruce (all species)	35 C cf/acre
True firs	35 C cf/acre
Douglas Fir	33 C cf/acre
Lodgepole Pine	32 C cf/acre

This completes the study of data from program 1, the first of two programs used to analyze the B.C. Forest Service volume/age curves.

CHAPTER IV

AN ANALYSIS OF VOLUME/AGE CURVES: PROGRAM 2

The B.C. Forest Service did not make full use of their plot data in the formulation of the volume/age curves. Calculation of values of normality through degree of stocking, stand density and average stand diameters would have enabled forest land managers to be more precise in the application of the curves; therefore, estimates of the variables need to be made.

This task is an important one because growth rates (especially in merchantable terms), hence rotation determination, are affected by degree of stocking and density within areas stocked. Since volume/age curve yields are empirical, or averages of conditions sampled at random, an attempt is made here to provide an indication of normalities, densities of stocking expressed as numbers of trees per acre according to certain size limits, and average diameter ($\bar{D}$) in inches at breast height. The grouped growth types chosen for this assessment are Douglas Fir, Spruce and Lodgepole Pine.[5]

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[5] For a description of the species represented see the 1957 B.C. Forest Service Inventory (B.C. Forest Service, 1958).

1. Data Processing - Program 2

Data from Appendices I and II were combined to form the basis of program 2 (Appendix IV). The objective of this program was to summarize the values of the variables listed in Chapter III, for a number of site index classes, for the three grouped growth types studied. From these summaries it was possible to produce the following estimates:

A. Degree of stocking, from the comparison of volume/age yields to a standard;

B. Numbers of trees per acre (NT) according to certain size limits, average stand diameter ($\overline{D}$) and spacing equivalence;

C. Averages for RC, P.A.I. and YC.

It should be noted that program 2 sorted each card (representing one volume/age curve) into one of a number of site index classes based on assumed medians for the site classes: good, medium, poor and low. These were adopted (in feet at 100 years) as follows:

0 - 30	91 - 110
31 - 50	111 - 130
51 - 70	131 - 150
71 - 90	151 plus

To facilitate the analysis the following site index classes were chosen:

Species predominant	Site index class midpoint
Douglas Fir	80
	100
	120
	160
Spruce (all species)	60
	80
	100
Lodgepole Pine	60
	80
	100

Variation within the data was reduced by the sorting criteria used; although the problem of mixed U. limit remained. It was known that $\overline{X}RA$ values for both U. limits 1 and 2 were almost the same. It was not known though, whether the same outcome applied to $\overline{X}YA$, the yield in C of coinciding with RA years. So 12 out of 96 Douglas Fir curves for the four site index classes decided upon were removed from the data. The 84 remaining were classified as U. limit 2 only. A comparison of the $\overline{X}YA$ value for U. limit only 2, as opposed to that for mixed U. limits, showed a five percent decrease in the yield per acre. Since this difference did not jeopardize the objectives of the analysis the mixed U. limit data were retained.

This difference was even less significant for the other species because only 7 out of 116 spruce curves and 6 out of 120 lodgepole pine curves were classified as U. limit 1. This leads to the assumption that the minimum diameter limits applicable in this Chapter are 7.1 and 11.1 inches dbh respectively. This assumption is also extended to the other variables such as RB, RC, YB and YC.

Having qualified the data to be used it is now possible to indicate some estimates produced:

A. Degree of stocking - The degree of stocking determined for the three species is an attempt to answer the question: What relationship do the yields per acre at rotation age, indicated by the three species, have with respect to acknowledged standards? To do this it was necessary to choose a standard (normal) yield table from among several, at times. Another task was to adjust yields to a common site and utilization standard from either the standard table or the volume/age curve summaries to make valid comparisons. With the standard (normal) quantities available, degree of stocking was then expressed as a percent of standard.

a) Douglas Fir: Table lX indicates that the volume/age curves, within the four site index classes listed, are at least 20 percent below standard for YA values. In another 20 years or so YB values indicate standard yields, at least for the lower site index classes. Because of the small number of curves represented in the better site index classes no conclusions are drawn. Better site index classes indicate substandard yields since good sites are expected to approach the standard yield faster than poor sites.

b) Spruce: Table X for spruce types shows that the YA yield is virtually normal for site index 60, and that the YBP yield is, in fact, normal. Volume/age curve yields for site index 100 are 90 and 92 percent of normal, respectively.

Standard quantities in this case were interpolated from Forest Service 1936 normal yield tables for Engelmann Spruce. Stanek's (1966) tables were also considered since they depicted yields from "reasonably well-stocked stands". A comparison of the three sources shown in Figure 6 indicates the use of the former tables in terms of Engelmann Spruce. Seemingly, they offer greater stocking by volume over a larger proportion of site index values. Stanek's values were adjusted from total to net values for decay using decay figures from the Forest Service inventory (1958). In addition, volume/age curve yields at 100 years ($\bar{X}$VP100) were adjusted by comparing them to

TABLE IX COMPARISONS OF $\bar{X}$YA AND $\bar{X}$YBP YIELDS WITH STANDARD QUANTITIES FOR RA AND RB YEARS -- DOUGLAS FIR V.A. CURVES.

SITE INDEX CLASS MID PT.	$\bar{X}$RA Years	$\bar{X}$RB Years	$\bar{X}$YA Ccf/ac	YN Ccf/ac	% of YN (Standard)	$\bar{X}$YBP Ccf/ac	YN Ccf/ac	% of YN (Standard)	No. V.A. Curves
80	98	125	31	49	76	57	59	97	52
100	82	105	39	63	62	77	77	100	36
120	87	104	70	95	74	83	107	78	5
160	65	81	92	111	83	113	135	84	3
AVE.	90	115	--	*	--	**	--	--	(96)

* McArdle and Meyer (U.S.D.A., 1949)

** $\bar{X}$YBP: the yield at RB years adjusted to compare with minimum diameter limit of 7.1 inches associated with RA years.

the Forest Service (1936) tables at the 7.1 inch level. This provided factors which,when applied to the one inch values in the 1936 tables, produced a comparable estimate for the volume/age curve yields.

c) Lodgepole Pine: Table XI indicates that the volume/age curves for this group of growth types resulted in only 61 to 79 percent stocking when compared to standard quantities, at the RA stage at least. These ranged from 62 to 67 percent for the RB values. Lee (1967) described seven Lodgepole Pine yield tables but concluded that the B.C. Forest Service (1936) tables present merchantable values, rather than total cubic volumes required for calculating the degree of stocking in these terms.

From a comparison of the data presented, Spruce types exhibit yields closer to standard than either Douglas Fir or Lodgepole Pine types, for the site index classes analysed. It cannot be denied that these estimates of the degree of stocking, on the basis of merchantable yields per acre in C cf, are nothing more than indications. First of all, the standard tables applicable to Spruce include Engelmann Spruce data alone. Secondly, volume/age curve yields for all three species types are calculated to a six inch top, rather than to the tip of each tree in the basic data. Thirdly, the volume/age

TABLE X COMPARISONS OF $\bar{X}YA$ and $\bar{X}YBP$ YIELDS WITH STANDARD QUANTITIES FOR RA AND RB YEARS - SPRUCE V.A. CURVES.

SITE INDEX CLASS MID PT.	$\bar{X}RA$ Years	$\bar{X}RB$ Years	$\bar{X}YA$ Ccf/ac	YN Ccf/ac	% of YN (Standard)	$\bar{X}YBP$ Ccf/ac	YN Ccf/ac	% of YN (Standard)	NO. V.A. Curves
60	120	144	27	28	96	33	33	100	37
80	93	121	35	38	92	44	49	90	39
100	82	103	46	51	90	55	60	92	40
AVE.	98	122	--	*	--	--	--	--	116

* B.C. Forest Service (1936).

Figure 6· Comparison of yields from three sources for spruce types in British Columbia at 100 years, for trees 1 inch and larger in d·b·h·, less decay·

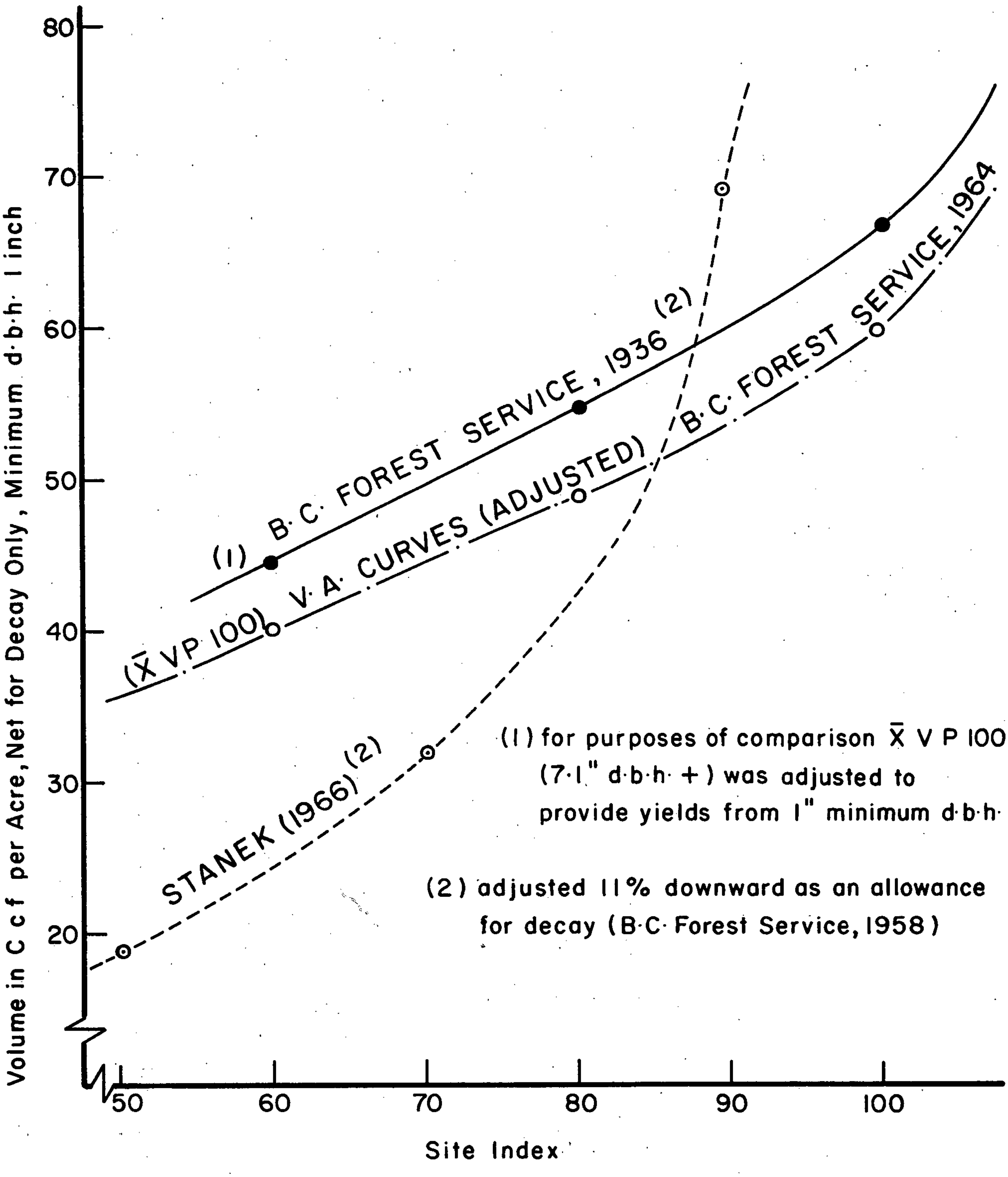

TABLE XI · COMPARISONS OF $\bar{X}$YA and $\bar{X}$YBP YIELDS WITH STANDARD QUANTITIES FOR RA AND RB YEARS - LODGEPOLE PINE V.A. CURVES.

SITE INDEX CLASS MID PT.	$\bar{X}$RA Years	$\bar{X}$RB Years	$\bar{X}$YA Ccf/ac	YN Ccf/ac	% of YN (Standard)	$\bar{X}$YBP Ccf/ac	YN Ccf/ac	% of YN (Standard)	NO. V.A. Curves
60	96	124	30	38	79	36	55	65	57
80	86	116	41	57	72	52	78	67	61
100	82	112	39	64	61	50	81	62	2
AVE.	91	120	--	*	--	--	--	--	120

* B.C. Forest Service (1936).

curve data are summarized by approximated site index class midpoints. The application of decay factors to the B.C. Forest Service (1936) tables for Engelmann Spruce (reduction factor of 11 percent) and Lodgepole Pine (reduction factor of 6 percent) may be questioned as well. No factor was applied to Douglas Fir standard yields. McArdle and Meyer (U.S.D.A., 1949) stated that decay losses in stands less than 100 years old are less than 2.5 percent of the total merchantable volume of the stand. In spite of the various shortcomings indicated here the estimates of degree of stocking provided, on the basis of yield, calculated from trees with a minimum dbh limit of 7.1 inches, appear to be reasonable.

B. Numbers of trees per acre (NT), average stand diameter ($\bar{D}$) and spacing - Numbers of trees per unit area are a significant factor in the determination of merchantable volumes (Smith, 1958, 1963, 1966, Smith, Ker and Csizmazia, 1961). To show this, Smith (1958) has said that initially wide spacing of Douglas Fir on site index 110 may produce a stand with greater volume per tree than in one grown at close spacing on lands of site index 150.

In a fully stocked area (complete crown closure) stand density can be represented by dense thickets of trees of abnormally small diameters, by a normal well-distributed stand associated with standard average diameter, or by a noticeably open stand in which average diameter is larger than expected for a particular age. This must be one reason why degree of stocking is better related to volume productivity rather than to numbers of trees. The former measure changes little over a range of stand density. This is true also of an allied measure, basal area per acre.

Within descriptions of interaction between yield and growing space care must be taken to differentiate total and merchantable volume. Broadly speaking, one may expect the latter measure to be at a maximum in the 'open' forest state, and at a minimum in the 'dense' forest situation. The behaviour of merchantable yield in the manner just explained is the foundation of the work first undertaken by Smith (1958) and summarized with others by Osborn (1968), in the development of spacing criteria within the objectives of intensified forest management. And, this approach leads to the attempt here to estimate numbers of trees and $\bar{D}$. These values may then be used to determine the capacity of growth per acre over time, as compared to the average values estimated from the volume/age curve yields.

Changes in $\bar{D}$, or average dbh in inches, of all measured trees in a stand, are the main cause of merchantable volume variation with spacing. The O (open) to N (normal) concept of stand development (Smith, Ker and Csizmazia, 1961) relies on the fact that open spacing produces a larger $\bar{D}$, hence greater volume per tree than the reverse situations. This means that today foresters require not only yield values alone, but also estimates of $\bar{D}$ and associated spacing ratios to provide targets of maximum merchantable growth attainable. In order to provide indications of the 'harvest chance' $\bar{D}$ estimates should be accompanied by estimates of dispersion from the average.

One substitute for the lack of this desired information has been the estimation of standard yields through the simulation of forest stand growth and yield. This is accomplished through the use of multiple regression techniques and electronic computers (Smith, 1967b). The theses of Newnham (1964), Stanek (1966), and Lee (1967) provide the basis for predicting growth and yield in this manner. The data inputs emanate from measurements obtained from individual trees, rather than from the traditional plot. At first hand there appears to be an obvious weakness to the formulation of volumes over thousands of acres on the basis of a thirty by thirty matrix, or so. The point is that this technique isolates the variables determining the required measures. These isolated variables may then be used by forest managers to develop the criteria for improved forest management objectives. Again, estimates of these variables attached to yields from natural, unmanaged stands, as in the case of volume/age curve figures, would provide forest managers with improved criteria for producing maximum yields of wood. Smith (1968) has described various ways of approaching such requirements.

The needs are thus defined. The next portion of the analysis describes the techniques for determining indications of NT, $\bar{D}$ for the three species groups.

a) Techniques used for determining NT and $\bar{D}$

Two methods are used to determine NT for a number of diameter limits. Given the volume per acre in C cf according to these limits, it then becomes a matter of determining a suitable average volume per tree ($\bar{V}$). By dividing $\bar{V}$ into the appropriate volume, the equivalent number of trees per acre is found. The two methods of determining NT are, firstly, that propounded by Smith (1967a), and, secondly, the incorporation of Spurr's (1952) combined-variable approach used by Smith and Breadon (1964) as a means of volume estimation for British Columbia forests. Both methods provide $\bar{V}$ per tree for application to volumes per acre as shown in Table XII.

Before describing the two methods of obtaining $\bar{V}$ per tree it should be emphasized that this table

TABLE XII YIELDS PER ACRE IN Ccf FOR DOUGLAS FIR, SPRUCE AND LODGEPOLE PINE TYPES FOR SELECTED SITE INDICES.

SPECIES PREDOM.	SITE INDEX	RA YEARS	VOLUME Ccf/ac 3.1"+	7.1"+	11.1"+	PERCENT 1.1"+	11.1"+	RB YEARS	VOLUME Ccf/ac 3.1"+	7.1"+	11.1"+	PERCENT 7.1"+	11.1"+	NO. V.A. CURVES
D. FIR.	80	98	36	31	21	86	58	125	41	37	30	90	73	52
	100	82	44	39	29	89	53	105	55	49	39	89	71	36
	120	87	78	70	57	90	73	104	89	83	72	93	81	5
	160	65	104	92	79	88	76	81	124	113	102	91	82	3
	MEAN	90	43	38	28	87	65	115	51	46	38	90	74	Σ.96
SPRUCE	60	120	33	27	16	82	48	144	38	33	21	87	55	37
	80	93	41	35	23	85	56	121	52	44	32	85	62	39
	100	82	51	46	34	90	67	103	60	55	45	92	75	40
	MEAN	98	42	36	25	86	59	122	50	44	33	88	66	Σ.116
LODGE-POLE PINE	60	96	39	30	13	77	33	124	43	36	16	84	37	57
	80	86	47	41	20	87	42	116	65	52	32	80	49	61
	100	82	50	39	20	78	40	112	53	50	32	94	60	2
	MEAN	91	43	36	17	82	40	120	54	44	24	82	44	Σ.120
VARIABLES		$\bar{X}$RA	*	$\bar{X}$YA	$\bar{X}$YB			$\bar{X}$RB	*	$\bar{X}$YBP	$\bar{X}$YB			

* Extrapolated after comparison with Fligg's (1960) tables.

contains the starting data for this Chapter. The volumes for each diameter limit are used to determine a reference volume (the value equivalent to 100 percent in each case). In Table XII this reference volume is provided by the quantity shown for trees 3.1 inches or larger. Why the particular proportion? Because the best source of data for converting volumes from trees 7.1 inches or larger to total were shown in Fligg's (1960) empirical yield tables[6] for the three species analysed. Here, the total volume per acre was the equivalent of volumes from trees 3.1 inches or larger in dbh.

To make this transformation it was necessary to match a volume/age curve yield value (7.1 inches dbh and larger) with the nearest Fligg equivalent. Since there were a number of growth types and four site classes to choose from it was difficult at times to choose the closest one. To obtain a value for this utilization level it was necessary to interpolate between the 3.1 inch and 9.1 inch proportions in the Fligg tables.

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[6] Both Fligg's (1960) tables and the more recent volume/age curve yields are derived from common data.

Next a factor was developed from a comparison of the two figures. This, in turn, was applied to the Fligg 3.1 inch proportion to convert this to a volume/age curve equivalent. The result of this may be seen in Table XII for both RA and RB rotations.

The volumes per acre set out according to the proportion within each diameter limit were the dividends into which $\bar{V}$ per tree was divided. This calculation produced numbers of trees within the specified diameter limits. The two methods used to find $\bar{V}$ per tree are described here.

The first method (after Smith, 1967a) is set out as follows:

$\bar{V}$ per tree, cf $= \bar{B} + b\,\bar{H}$, where

$\bar{B}$ = basal area per tree in square feet;

$\bar{H} = \dfrac{\text{site index}}{100} \times$ rotation years, in feet;

to obtain $\bar{B} = \dfrac{\text{basal area/acre}}{\text{NT per acre}}$

find from Smith (1967a) the value for NT/square foot of basal area X basal area per acre.

Where basal area/acre $= \dfrac{(15.4)^2}{(CW/D)^2}$

and CW is crown width in feet; D is average diameter of the stand in inches;

given (Smith, 1967a) for: Dense density, CW/D = 0.6

Normal density, CW/D = 1.0

Open density, CW/D = 2.0

for the three species analysed.

and D is equivalent to $0.125\bar{H}$, dense density

$0.02\bar{H}$, normal density

$0.33\bar{H}$, open density

an estimate of $\bar{D}$ (of average D^2) is needed to obtain NT/square foot of basal area from Table VIII (Smith, 1967a);

then 'b' = regression constant; varies with species. From Smith (1967a) the following values were used:

Douglas Fir	=	0.38
Spruce	=	0.39
Lodgepole Pine	=	0.45

With the completion of NT calculations using method 1, a second approach was tested. This became method 2, the combined-variable approach. In this instance $\bar{V}$/tree = a + b ($\bar{D}^2$ $\bar{H}$/100). The steps to obtain this are set out below:

'a' and 'b' are regression constants; (Smith and Breadon, 1964)

then ($\bar{D}^2$ H/100) is calculated from $\bar{D}$ for three classes of density associated with the outline of method 1;

from the tables of Smith and Breadon (1964) the resulting value of each $(\bar{D}^2\ \bar{H}/100)$ is used to determine the appropriate equation for the circumstances experienced;

$\bar{H}$ for the calculation is the same for both methods 1 and 2.

The use of the size of $(\bar{D}^2\ \bar{H}/100)$ in the choice of a particular equation was confusing. The value found did not always fit equations given. Next, different equations were required for $\bar{V}B$ determination, but in some cases the result was a smaller $\bar{V}B$ value rather than an expected increase due to the older, larger trees. In a third approach the three estimates of $\bar{D}$ used in methods 1 and 2 were replaced with a single, unclassified value. This $\bar{D}$ was selected on the basis that the size distribution in Table XII approximated the normal distribution[7]. The percentages obtained (using the 3.1 inch level as a base of 100 percent) were then used to determine $\bar{D}$. For instance,

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[7]Newnham (1964) and Lee (1967) indicated that trees in a stand may follow one of a number of predictable distributions by diameter classes. Newnham (1964) stated that if n is sufficiently large the normal distribution may be used to approximate any of these other distributions.

if 28 percent of the volume in a site index class lies between 7.1 and 11.1 inches, $\bar{D}$ becomes 7.1 inches + (0.50/0.28)(4 inches) or 14.2 inches. Values such as this, known as $\bar{D}'$, are indicated in Table XIII.

It was possible, by comparing the diameter values associated with dense, normal and open densities of methods 1 and 2, to classify $\bar{D}'$ values. Again reference is made to Table XIII.

To obtain final values of $\bar{V}$ per tree the interim values (not shown) for all three methods were multiplied by the following:

Douglas Fir types	:	0.86
Spruce (all species) types	:	0.84
Lodgepole Pine types	:	0.89

These factors originated from Browne's (1962) tables of cubic-foot volumes for British Columbia. These converted $\bar{V}$ figures to close utilization, less decay.

This completes a description of the three methods of estimating $\bar{V}$/tree. The results of using these values, together with the volume proportions of Table XII, to determine NT (numbers of trees per acre) and $\bar{D}$ will be considered next.

b) Results

(1) NT, $\bar{D}$

Appendix III contains tables of numbers

TABLE XIII AVERAGE STAND DIAMETER FOR TREES 7.1 INCHES AND LARGER, BASED ON THE NORMAL FREQUENCY DISTRIBUTION, AND LABELLED AS $\bar{D}'$.

SPECIES PREDOM.	SITE INDEX	STAND * DENSITY	RA YEARS	$\bar{D}'$A INCHES	RB YEARS	$\bar{D}'$B INCHES
			TREES 7.1 INCHES +			
D. FIR	80	D - N	98	14.5	125	18.9
	100	D - N	82	12.6	105	18.2
	120	D - N	87	18.9	104	23.8
	160	O - N	65	23.8	81	29.3
	Av.	D - N	90	16.2	115	19.6
SPRUCE	60	O - N	120	13.0	144	13.4
	80	D - N	93	14.0	121	15.8
	100	D - N	82	15.8	103	18.9
	Av.	N	98	14.5	122	16.2
LODGEPOLE PINE	60	O - N	96	11.6	144	14.5
	80	D - N	86	11.5	121	13.6
	100	D - N	82	12.4	103	13.0
	Av.	D - N	91	11.9	122	12.4

* D - N: dense to normal

O - N: open to normal

N : normal

of trees and $\bar{D}$ for the three species groups considered. Because of the three methods tested there are three choices of NT possible for each site index class studies. Figures 7, 8 and 9 summarize the choices for site index 100 from the tables in Appendix III. This site index was chosen since it was represented in all three species groups.

In comparing the three methods of obtaining indications of NT it may be said that method 1 (after Smith, 1967a) provided estimates greater than either of the other two methods. In fact the line dense-1 for all three species was reduced 50 percent to indicate a more realistic relationship between NT and age. Method 3 (after Smith and Breadon, 1964, and with use of $\bar{D}$) values were positioned between the normal values of methods 1 and 2 in all cases. Method 2 provided the smallest estimates of NT. The comparisons discussed are shown in figures 7, 8 and 9 for trees 7.1 inches and longer. The source of data is tables of numbers of trees from Appendix III.

These figures provide a means of ranking the various NT levels determined. There is no criterion available to be sure which level is applicable to $\bar{X}$YA values from the volume/age curves. Figures 7, 8 and

FIGURE 7: Comparisons of three methods of estimating numbers of trees per acre, for various stand densities, considering D. fir types of site index 100 from volumes 7.1" and larger.

Method 1: $\bar{V} = \bar{B} + b\bar{H}$

" 2: $\bar{V} = a + b(\bar{D}^2 H/100)$

" 3: $\bar{V} =$ " " alternate $\bar{D}$

———————— = Normal density

- - - - - - - - = Open density

—— —— — = Dense density

—oo—oo—o = Mc. Ardle & Meyer SI 100

x x x x x x x x = Unclassified density

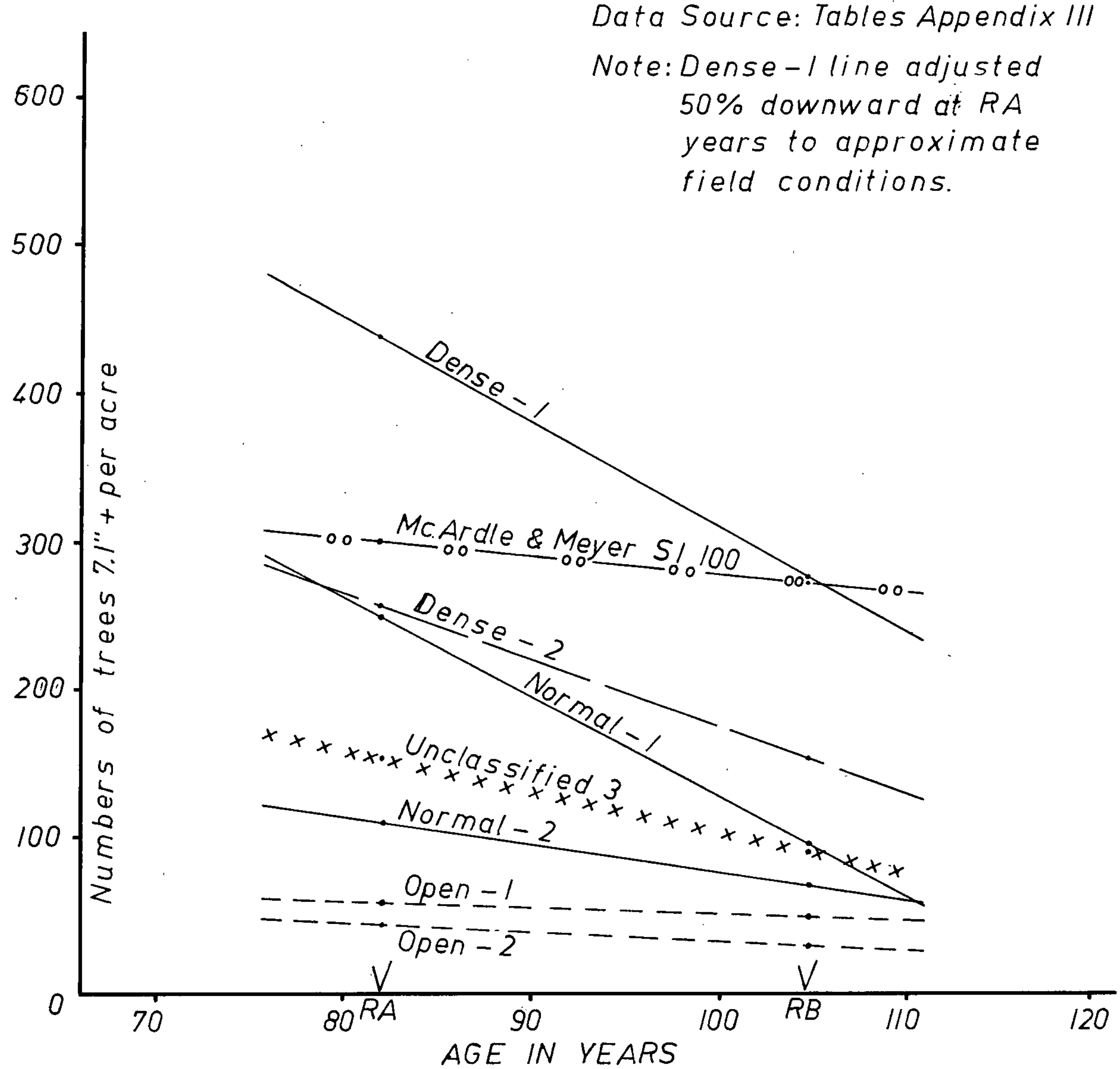


FIGURE 8: Comparisons of three methods of estimating numbers of trees per acre, for various stand densities, considering spruce types of site index 100 from volumes 7.1" and larger.

Method 1 : $\bar{V} = \bar{B} + b\bar{H}$

" 2 : $\bar{V} = a + b(\bar{D}^2H/100)$

" 3 : $\bar{V} =$ " " alternate $\bar{D}$

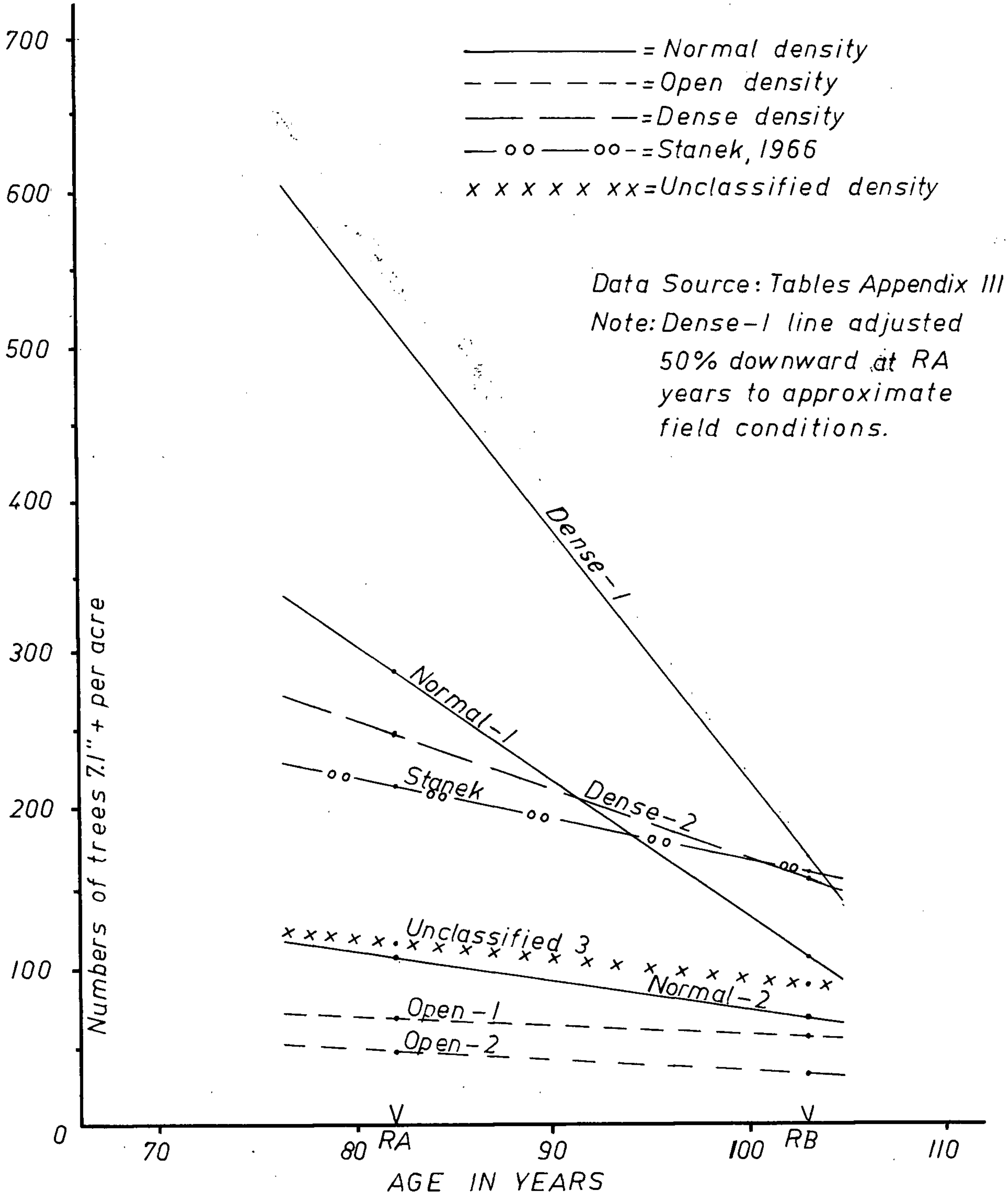


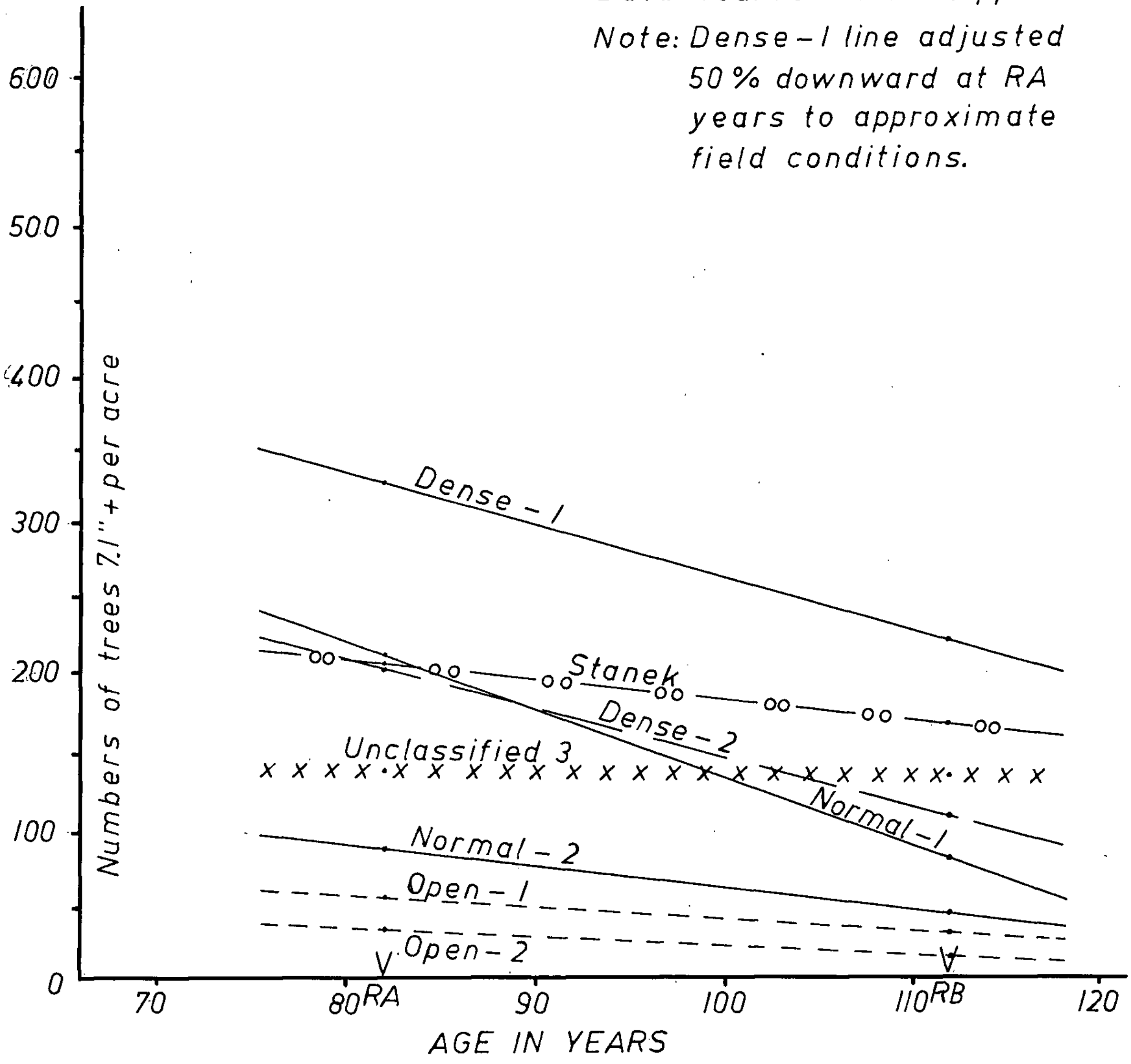
FIGURE 9: Comparisons of three methods of estimating numbers of trees per acre, for various stand densities, considering lodgepole pine types of site index 100 from volumes 7.1" and larger.

Method 1: $\bar{V} = \bar{B} + b\bar{H}$
" 2: $\bar{V} = a + b(\bar{D}^2H/100)$
" 3: $\bar{V} =$ " " alternate

——————— = Normal density
– – – – – – – = Open density
—— —— – = Dense density
—oo——oo— = Stanek (1966)
x x x x x x x = Unclassified

Data Source: Tables Appendix III

Note: Dense-1 line adjusted 50% downward at RA years to approximate field conditions.



9 indicate median values of NT, 7.1 inches and larger for the three methods as follows (site index 100): 150 trees per acre for Douglas Fir types, 115 trees per acre for Spruce types, and 138 trees per acre for Lodgepole Pine types. In each case, at the RA age, method 3 is in the median position.

Method 3 also maintains this position at the RB age, with one exception. In the case of Lodgepole Pine types, method 1 (normal) is the median value.

The NT estimates indicated are further removed from the standard than the degree of stocking values determined in Tables X, XI and XII. These estimates by themselves cannot indicate the density of stocking (Lee, 1967). This added information can only be determined from a size qualification. Accordingly, $\bar{D}$ is used to qualify sizes of trees. Again, no criterion exists to choose which of the two D figures ($\bar{D}$ and $\bar{D}'$) is the correct one. The former has three alternative values, one for each of the three stand density classes. They are found in Appendix III, Tables I, II and III. The latter, an average value for each species type, is found in Table XIII. Since $\bar{D}'$ is found by assuming there to be a normal distribution of NT with diameter classes, for a given D, conceivably the resulting $\bar{D}'$

may be used as the applicable volume/age curve value. Comparing $\overline{D}$ to $\overline{D}'$ values the conclusion is that the three species types exhibit dense to normal stand density within the area stocked on each acre, for the rotation ages determined.

The two results, then, of studying methods of obtaining NT and $\overline{D}$ are: firstly, that the volume/age curves analysed are stocked below the level of standard yields (close utilization limits); secondly, that by replacing the assumed values in the methods used to indicate NT and D with field sample values important qualifications to the volume/age curve yields may be found.

(ii) Spacing Equivalence

Table XIV indicates the spacing equivalence of NT values in Tables I, II and III, Appendix III. Method I (after Smith, 1967a) values were used since they offer comparisons between stand densities. Each extrapolated NT figure, identified with the 3.1 inch level, was divided into 43560 square feet. The square root was then obtained and entered into Table XIV. It is assumed for the purpose of the calculations made that the trees were uniformly spaced on each acre.

As an example of the information provided by Table XIV (site index 100, normal density class)

TABLE XIV: NUMBER OF TREES 3.1" + PER ACRE EXPRESSED AS SPACING EQUIVALENCE IN FEET^2 FOR D.FIR, SPRUCE AND LODGEPOLE PINE TYPES REVIEWED (METHOD 1, AFTER SMITH, 1967a).

STAND DENSITY	SITE INDEX	D. FIR TYPES SPACING EQUIVALENCE		SPRUCE TYPES SPACING EQUIVALENCE		LODGEPOLE PINE TYPES SPACING EQUIVALENCE	
		Feet^2 at RA	Feet^2 at RB	Feet^2 at RA	Feet^2 at RB	Feet^2 at RA	Feet^2 at RB
O				19.6	27.9	17.8	23.8
N	60			8.7	20.7	8.5	13.0
D				6.6	9.8	5.9	7.6
O		24.6	31.8	21.0	28.1	20.3	26.5
N	80	13.4	22.5	12.4	19.9	10.7	18.7
D		7.1	11.5	7.2	10.2	7.0	9.6
O		24.8	28.1	23.3	26.9	25.3	36.9
N	100	12.4	19.9	11.7	19.1	12.6	22.8
D		6.6	12.6	6.2	12.1	6.7	14.4
O		23.5	25.3				
N	120	16.6	18.1				
D		8.6	9.8				
O		20.3	23.9				
N	160	14.3	17.0				
D		7.4	9.3				
O		24.4	29.5	21.6	27.6	19.8	25.7
N	AV	13.5	21.0	11.3	19.8	9.9	16.9
D		7.1	11.8	6.6	11.0	6.7	9.0

Douglas Fir types show a spacing of 12.4 feet by 12.4 feet at RA years. This spacing produces an average stand diameter (Table I, Appendix III) of 16.4 inches at 82 years, the culmination point of the mean annual increment in cubic feet for trees 3.1 inches dbh or larger. Comparable values for Spruce types are 11.7 feet, 16.4 inches (Table II, Appendix III) dbh at 82 years. Lastly, for Lodgepole Pine types these values are 12.6 feet, 16.4 inches dbh (Table III, Appendix III) at 82 years. The coincidence of identical $\bar{X}$RA values for the three species groups, site index 100, is noted also.

Further results in the form of $\bar{X}$RC, $\bar{X}$P.A.I. and $\bar{X}$YC values for the three species groups are introduced next.

C. RC, P.A.I., YC

a) $\bar{X}$RC: Table XV indicates the age at which volume increment equals volume decrement. This is 184 years for the Lodgepole Pine site index classes, 215 years for the Spruce site index classes, and 239 years for the Douglas Fir site index classes, studied. These values define the natural rotation for the average site index.

b) $\bar{X}$P.A.I. (GRPT): Table XV also indicates that the periodic annual increment in percent (alternatively

TABLE XV: ROTATION AGE CORRESPONDING TO MAXIMUM VOLUME PER ACRE, M.A.I., AND P.A.I., FROM TREES 7.1 INCHES AND LARGER, FOR DOUGLAS FIR, SPRUCE AND LODGEPOLE PINE TYPES.

Species	DOUGLAS FIR TYPES					SPRUCE TYPES					LODGEPOLE PINE TYPES				
Site Index	No. Curves	$\bar{X}$RC Years	$\bar{X}$YC Ccf/ac	$\bar{X}$MAI Ccf/ac	$\bar{X}$PAI %	No. Curves	$\bar{X}$RC Years	$\bar{X}$YC Ccf/ac	$\bar{X}$MAI Cf/ac	$\bar{X}$PAI %	No. Curves	$\bar{X}$RC Years	$\bar{X}$YC Ccf/ac	$\bar{X}$MAI cf/ac	$\bar{X}$PAI %
60						37	226	36	22	1.6	57	182	39	31	1.3
80	52	231	46	32	1.3	39	218	51	38	1.3	61	186	58	48	1.2
100	36	232	62	49	1.2	40	203	69	57	1.2	2	166	56	48	1.2
120	5	314	124	86	1.1	-	-	-	-	-	-	-	-	-	-
160	3	323	187	143	1.0	-	-	-	-	-	-	-	-	-	-
AV.		239	60	45	1.2	-	215	52	39	1.4	-	184	49	40	1.2

growth rate percent) varies from 1.2 to 1.4 percent, simple interest. These values are obtained from the differences in volume between VP50 and VP100, divided by 50 years times VP50, then the result multiplied by 100.

The highest values occur in the lowest site index classes, contrary to what may be expected. The explanation for this stems from the behaviour of volume/age curves defining low sites. In these areas the RA value and VP100 value corresponded closely. In the case of higher sites VP100 tended to be found much later on the curve than the RA value.

c) $\bar{X}$YC: Table XV also indicates the range of maximum yields for trees 7.1 inches and larger, on a per acre basis, close utilization standards. For the site index classes studies Douglas fir types yield an average of 60 C cf per acre, Spruce types 52 C cf per acre, and Lodgepole Pine types 49 C cf per acre.

2. Discussion and Conclusions

This Chapter has attempted to provide estimates of degrees of stocking, on the basis of merchantable volume per acre, to close utilization standards. Added to these are ranges of estimates for numbers of trees per acre to given diameter limits, average stand diameters and other variables. The basic data for all these estimates originate from the B.C. Forest Service growth and yield activities. Until the assumptions made in this study are replaced by actual values the present indications must suffice.

There were instances of discrete behaviour in the summary data. This made it more difficult to draw logical conclusions. For one thing the inverse relationship of site index to RA determined from program 1 was not observed with program 2 on all occasions. Table XII values for Douglas Fir RA for instance do not support this finding throughout the range of site index. In another area it is known that numbers of trees per acre decrease with increasing site index, after a certain age. This depends upon the species being considered. For Douglas Fir, numbers of trees per acre start to decline at about one hundred years on poor sites, somewhat earlier on higher sites (McArdle and Meyer, 1949). The data observed in Appendix III failed to behave in this manner.

In the first case the problem was felt to be a result of insufficient sample sizes in the higher site index classes. In the latter case, this was thought to be a result of insufficient sample size, as well as inaccurate assumptions in connection with some of the variables in the volume equations. Errors in the formulation of $\overline{V}$, then, would follow through into the NT values. For instance, $\overline{H}$ in all equations was determined by dividing site index by the pertinent RA value. This stems from the assumption (necessary to complete the calculation of $\overline{V}$) that the height/age relationship is linear. In fact, it is generally understood that the shapes of the curves are sigmoidal.

To test the adequacy of sample sizes, 't' tests (Freese, 1967) were applied to the site index classes studied. The results are shown in Table XVI. The basis for the tests were the class values for $\overline{X}$RA.

The results of the tests indicate that data for Douglas Fir site indices 120 and 160 are inadequate. Lodgepole Pine site index 100 requires further sampling as well.

The following conclusions, resulting from the analysis developed in program 2, are presented:

1. For the site index classes studied Douglas Fir types indicate degrees of stocking ranging from 62 to 83 percent of standard yields, for trees 7.1 inches dbh and larger;
2. For the site index classes studied Spruce types indicate degrees of stocking ranging from 90 to 96 percent of standard yields, for trees 7.1 inches dbh and larger;
3. For the site index classes studied Lodgepole Pine

TABLE XVI: CONFIDENCE LIMITS, AT THE 5 PERCENT LEVEL, ABOUT $\bar{X}$ RA AND $\bar{X}$ RB FOR DOUGLAS FIR, SPRUCE AND LODGEPOLE PINE TYPES, WITH P OF 0.95 THAT POPULATION MEAN FALLS WITHIN THESE LIMITS.

SPECIES	SITE INDEX CLASS MIDPOINT	LIMITS ABOUT $\bar{X}$RA YEARS	LIMIT ABOUT $\bar{X}$RB YEARS	REQUIRED SAMPLE SIZE
D.Fir Types	80	92< 98< 104	119< 125< 131	Adequate
	100	78< 82< 88	100< 105< 110	Adequate
	120	- 87 -	- 104 -	36 Curves
	160	- 65 -	- 81 -	36 Curves
Spruce Types	60	114<120< 126	138< 144< 150	Adequate
	80	88< 93< 98	116< 121< 126	Adequate
	100	78< 82< 86	98< 103< 108	Adequate
Lodgepole Pine Types	40	103<108< 113	123< 129< 135	Adequate
	60	93< 96< 99	119< 124< 129	Adequate
	80	82< 86< 90	112< 116< 120	Adequate
	100	- 82 -	- 112 -	36 Curves

types indicate degrees of stocking ranging from 61 to 79 percent of standard yields, for trees 7.1 inches dbh and larger;

4. Numbers of trees per acre, 7.1 inches dbh and larger, (site index 100) range from 32 to 1022 trees per acre, for the three species types;
5. The median values of NT, 7.1 inches and larger, developed from three methods of calculation for site index 100 are: 154 trees per acre for Douglas Fir types, 115 trees per acre for Spruce types, and 138 trees per acre for Lodgepole Pine types, all at the RA level of 82 years;
6. Of the three methods used to determine NT method 2 (after Smith and Breadon, 1964) rendered the lowest values in each density class. Method 3 (method 2 and using an alternative $\bar{D}$) provided the median values of NT listed above. Method 1 (after Smith, 1967a) provided estimates closest to the standard values for each species;
7. The various values of NT and $\bar{D}$ determined are, themselves, uncertain. The conclusion here is that methods are available to calculate these values. When the assumptions used in this Chapter are replaced by actual values from the basic data,

the methods used are capable of producing these necessary qualifications to volume/age curve data;

8. The age (RC) at which volume increment = volume decrement (natural rotation age) is 184 years for the Lodgepole Pine site index classes, 215 years for the Spruce site index classes and 239 years for the Douglas Fir site index classes, studied;
9. The P.A.I. (age 50 to 100 years) ranged from 1.2 to 1.4 percent for the species and site index classes studied, in terms of simple interest;
10. The m.a.i. (in cf to close utilization standards) for the three species types studied ranged from: 32 to 143 cf per acre for Douglas Fir types, 22 to 57 cf per acre for Spruce types and 31 to 48 cf per acre for Lodgepole Pine types;
11. The yield (in C cf to close utilization standards) at the culmination of the natural rotation (RC) for the three species types studied ranged from 46 to 187 C cf per acre for Douglas Fir, 36 to 69 C cf per acre for Spruce, and 39 to 58 C cf per acre for Lodgepole Pine types;
12. Douglas Fir types require more sampling in the upper site index classes. Another 70 curves or so are required in the high site range to be 95 percent

sure that the population mean falls within the confidence limits at the 5 percent level.

As a general conclusion it may be said that this Chapter has demonstrated methods for the calculation of NT and $\bar{D}$ values. The use of the basic data from which the volume/age curves were developed as an alternative to the assumptions made in this instance would produce worthwhile results. Then, not only would volume/age curves forecast yield, but they would also indicate the spacing to be used to develop material of specific diameter. This, in turn, would reflect the level of merchantability on a controlled basis. The forest land manager would remove much uncertainty from the setting of rotation lengths by being able to forecast average stand diameters[8] together with expected yields.

The ability to forecast tree size permits forest administrations to be warned in advance of that time at which the larger diameter trees are necessarily replaced with more numerous smaller ones. This fact alone is of the utmost importance if the management of British Columbia's forest

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[8]The B.C. Forest Service began superimposing $\bar{D}$/age curves (to qualified diameter limits) on all volume/age curves at about the same time that the available data were analysed for this study. This means that all curves since June 1968 include estimations of $\bar{D}$ curves according to the age classes sampled.

resource is to progress. The growth of world demand, not just for the materials of construction, but also even for the spiritual needs of the North American individual as well, require a philosophy of controlled expansion (Bunce, 1967; Haley, 1969) in this area. Again, the forecasting of size may help preclude the conservationist tendency to retard harvesting of British Columbia's forests to offset a possible shortage at some uncertain time in the future.

PART TWO

ECONOMIC CRITERIA

CHAPTER V

SOME FINANCIAL CRITERIA FOR THE DETERMINATION OF ROTATIONS

When Higgs (1911) recommended the one hundred year rotation for British Columbia forests the industry of the time was labour intensive. Labour was cheap and plentiful and equipment as yet undeveloped in the logging operations and sawmills of that era. As demand rose and the forest resource became more difficult to win, the introduction of capital intensive methods became necessary in order to increase productivity and maintain a competitive cost structure (Deutsch et al, 1959). In 1944 the Provincial cut of all products was 3.1 billion fbm (B.C. Forest Service, 1944) and in 1967 this figure had risen to 9.3 billion fbm (B.C. Forest Service, 1967). The profits were allocated in part to the purchase of automatic equipment in the processing plants, and into mobile steel spars and grapple loaders in the logging divisions. In 1944 an operator with three helpers loaded out 1.5 million fbm per month. His counterpart today loads out 2.5 to 4 million fbm per month with one helper using a mobile loader and grapple. Some of this saving in man-hours though is re-applied as mechanic's maintenance time. Capital cannot be deployed in this fashion without the guarantee of sufficient return to make the investment worthwhile. The volume of wood available for exploitation, then, becomes a limiting factor to this return on capital invested. Accordingly, the rotation length as a determinant of the annual allowable cut has a profound influence on the Province's industrial health.

This is most apparent in the Vancouver Forest District. Paillé (1968) has stated that here the annual production capacity of sawmills and pulpmills is 17.7 million C cf per year, but the volume of wood reaching these plants amounts to 7.7 million C cf per year. This is 44 percent of the operating capacity. The rationing of wood has a tendency to limit the amount of capital re-invested. The adoption of new technology in process engineering and systems techniques to improve productivity further may fail to occur in the areas of production that require these most.

In the long-run the net effect of this situation in the public realm may leave the next generation with a second growth stock of numerous small diameter trees for utilization in obsolescent plants capable of handling fewer, bigger trees. It becomes the purpose of this Chapter to present the economic criteria for the determination of rotations for British Columbia forests.

The first step will be to summarize a number of the important financial criteria; secondly, to outline briefly the goals and objectives of the organizations involved in forest management; lastly, to explore the economic implications of the use of mean stand diameter and other variables as a guide to rotation length before presenting certain conclusions.

The important financial criteria[9] considered are classed as having "zero time preference" or "time preference". The first class introduced contains criteria in which no recognition is given to the cost of maintaining capital assets over time. In other words the opportunity cost of capital inputs is ignored. The second class gives explicit recognition to these costs.

1. Zero Time Preference Criteria

A. Rotation determined by maximum net revenue -

Figure 10 illustrates that point in time at which maximum revenue earned from a final harvest is collected. This is designated by the rotation length R_1. The revenue quantity at

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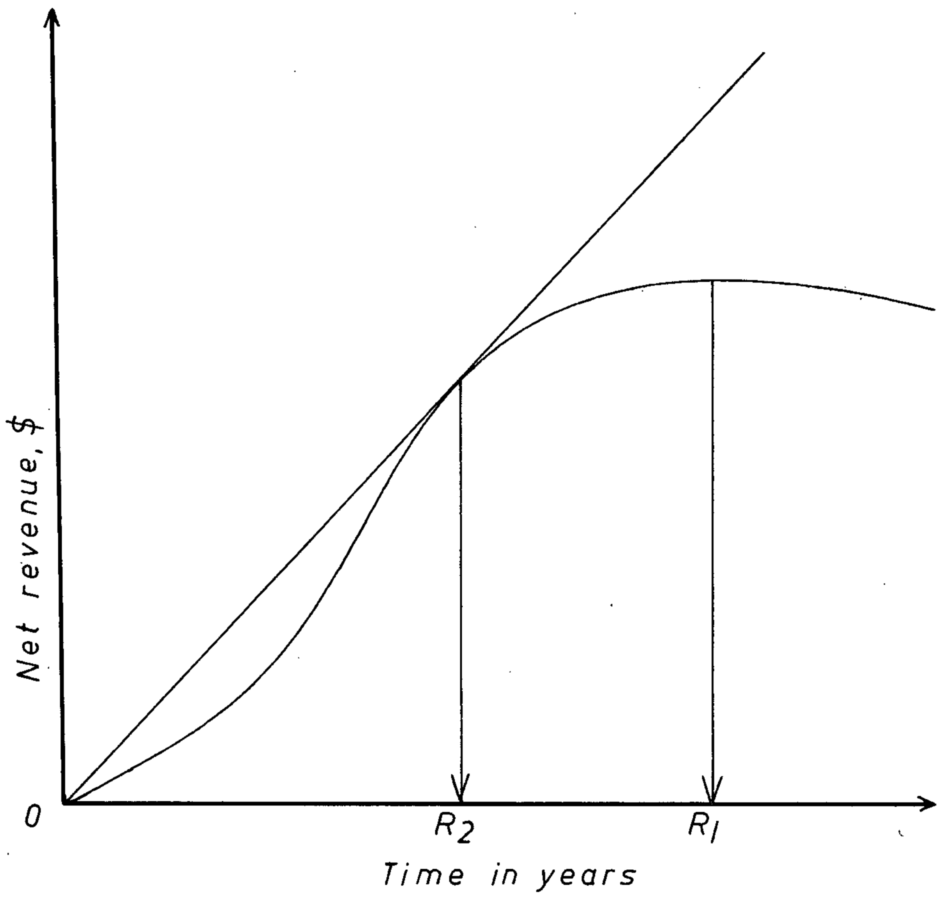
[9]Selected references: Duerr, 1960; Haley, 1964, 1966; Pearse, 1967; Haley and Smith, 1964; Gaffney, 1960; Dobie, 1966; Victor, 1968; Johnston *et al*, 1967.

FIGURE 10: Graphical comparison of rotations determined at the points of maximum net revenue (R_1) and maximum mean annual net revenue (R_2)



this time of final harvest is due to two factors: the first is that this position is also the point of maximum, merchantable volume per acre; secondly, the mean stand diameter is larger than at any previous time in the development of the stand because of the redistribution of growth following applied stumpage values because of grade and size improvements with time.

There are a number of disadvantages which make this criterion useless for management purposes. First of all it promotes extended rotation lengths. From Part One of this study it was shown that the equivalent rotation lengths ranged from 166 years to 314 years for the three commercial tree species analysed. The long time spans indicated then are neither practiced or practicable.

Next, this criterion ignores the times at which expenditures are made and revenues received. The usual preference of the business man and society generally for earlier rather than later returns is, therefore, ignored also.

Lastly, maximizing net revenue fails to indicate capital efficiency. Net revenue may be increased by new infusions of capital. These confuse decisions concerning the profitability of the alternative courses of action considered by concealing the profitability of the actual operation.

B. Rotation of maximum mean annual net revenue -

Figure 10 also illustrates this rotation criterion. The line tangent to the revenue curve indicates the point at which mean annual net revenue is maximized.

From the analysis completed in Part One of this study rotations determined from this criterion are approximately half the length of those determined from the first criterion mentioned.

This criterion is based on the maximization of the German Waldrente or forest rent, an approach adopted by one school of German and Swiss foresters in the last two centuries (Gaffney, 1960).

As a zero interest criterion it has the same drawbacks as the first one discussed. By neglecting the influence of compound interest no judgements may be made concerning economically desirable capital input levels, or the opportunity cost of the capital to start with. Haley (1964) stated:

> "...beyond a certain point, each additional increment of capital contributes less to the total income than did the preceding increment; that is the capital is subject to diminishing returns. Therefore, in determining the most profitable rotation the percentage return to capital must be considered if a rational answer is to be obtained."

C. Rotation of maximum accounting rate of return (single year) - For the purpose of this study the maximum accounting rate of return may be defined as the rate of an investment's average net income the ratio of average net income to the initial investment, expressed in percent. To qualify as a zero time preference criterion the accounting rate of return may apply to a single year only. This could be the first year, the first full year, or any other undefined year in a firm's history (Victor, 1968).

The advantages of such a criterion are: firstly, accounting rates of return are easily calculated; secondly, they are easily understood by management; thirdly, capital projects can be ranked and decisions made to accept or reject these projects. Against these are the ambiguities resulting from activities peculiar to one year but not the next. These may reflect costs incurred because of inclement weather, also a change in the market price for the commodities produced, for instance. Unless one is intimately aware of a firm's environment and capital policy one may make errors in decision - making based on accounting rates of return for single years.

The manipulation of the annual cut through the application of this criterion presents a flexible approach to forest management. This perhaps is the greatest advantage offered by the criterion of the accounting rate of return.

D. Rotation according to some desired payback period -

Victor (1968) defined the payback period as:

> "the measure of time required for the cash income from an investment to return the initial investment to the firm".

It is more important to dwell for a moment on the relation of the payback period to the rotation length[9a] rather than to the initial choice of the period itself. For example a pulpmill is financed with a twenty-year payback period in mind. Whether or not the investment in the mill is actually paid off during this period depends upon the maintenance of the cash inflow from sales of the product. These, in turn, are dictated by the quantity of raw material available, in other words by the annual cut as governed by the length of the rotation.

If increased demand for pulp, coincident with a higher sales price, temporarily enables the manager to increase the cash allocation to the logger, he in turn may decrease the $\bar{D}$ of the marginal tree to be logged. Stands bordering the

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[9a] The long time span, associated with rotation lengths eliminates the use of the payback criterion from the start.

merchantable class in the short run become merchantable themselves and so the rotation is shortened a certain amount in the process. Even if the accounting rate of return remains constant the increased sales volume will allow management to accelerate the payback period for as long as this favourable position is maintained. Of course the reverse situation is equally true.

The advantage of such manipulations are: firstly, the mathematics are simple; secondly, the process is easily understood by those people involved.

Several disadvantages are said to exist. The first is that there is no one period which will maximize the profits of the firm involved. Secondly, all receipts are weighted equally, regardless of when they occur. This means zero time preference, and therefore the rate of payback is ignored. In the case of two possible investments (equal risk) with a common ten-year payback period, and investment A providing receipts at twice the rate of investment B, there is no acceptable technique available to choose the one which will most enhance the firm's financial position.

In practice, firms use the payback period criterion to determine investment decisions given a number of alternatives within departments rather than at a level which encompasses a whole financial structure. In this sense the pulp mill example is misleading. One defence of the payback period is that it may supplement other investment criteria in the measurement of risk (Victor, 1968).

2. Time Preference Criteria

A. Rotation determined at the point of maximum internal rate of return

- Victor (1968) defined the internal rate of return as the discount rate which reduces the net present value of an investment exactly to zero. In other words the culmination of the rotation determined from this criterion occurs when the discounted net revenue (present worth) equals net discounted costs.

Given the following hypothetical situation on an operating unit (after Johnston *et al.*, 1967):

Year :	0	15	20	Present
Cash Flow ($):	-200	+80	+400	Worth ($)
Discounted at 3%	-200	+52	+222	+74
4%	-200	+44	+182	+26
5%	-200	+38	+150	-12

the internal rate of return is indicated between the present worth (V_0) values of +26 and -12 dollars. This associated with a discount value between 4 and 5 percent. If the figures given for interest and present worth values are graphed the final internal rate of return determined is 4.5 percent (Figure 11).

Because the calculation of the internal rate of return ignores costs outside the operation in question, part of which is the cost of maintaining an i value less than that obtainable in some other endeavour (the opportunity cost of capital), the designated rotation will be somewhat shorter than optimal.

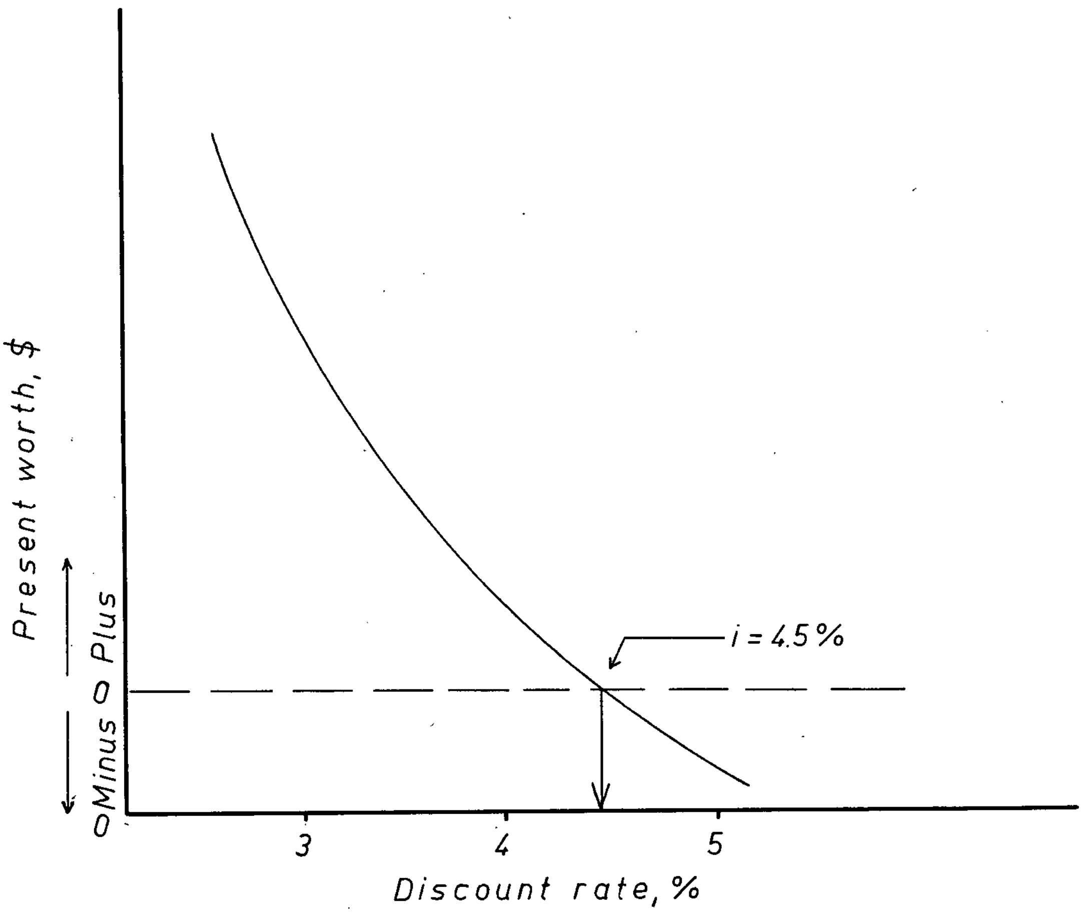
The advantages of this criterion are: (1) all cash flows are accounted for; (2) cash flows are weighted by the times in which they occur; (3) the length of the rotation is directly reflected in the value of the internal rate of return.

The principal disadvantage in the past has been the need to use iterative techniques in the calculations (Victor, 1968). Lately, though, computer programs have been developed which simplify these considerably (Love, 1965; Victor, 1968); although Gaffney (1960) concluded that certain weaknesses in the criterion had retarded its utility.

B. The maximum discounted net revenue criterion (N.D.R.)

This is the Faustmann (1849) approach. The age of culmination of the optimum rotation determined through this criterion occurs at the point where the marginal cost of holding the growing stock for one more period (year or cutting cycle) is just equal to the marginal revenue accruing to the

FIGURE II: Graphical determination of the internal rate of return from a hypothetical forest operation.



stand during that period. According to Haley (1964) the optimum rotation occurs where dg = Gi + a,

where: dg = the marginal value growth of the stand

a = annual land rent (the maximum amortized present value of net revenue)

G = capital value of the stand

i = the alternative interest rate, or opportunity cost of capital

Figure 12 illustrates the relationship of marginal cost and revenue to the optimum rotation.

The discount rate employed must be specified. It depends on such factors as the cost of capital and the amount of risk sustained by the investor. From Figure 12 the optimum rotation occurs at the point R_1. The point R_2 is ignored for the moment.

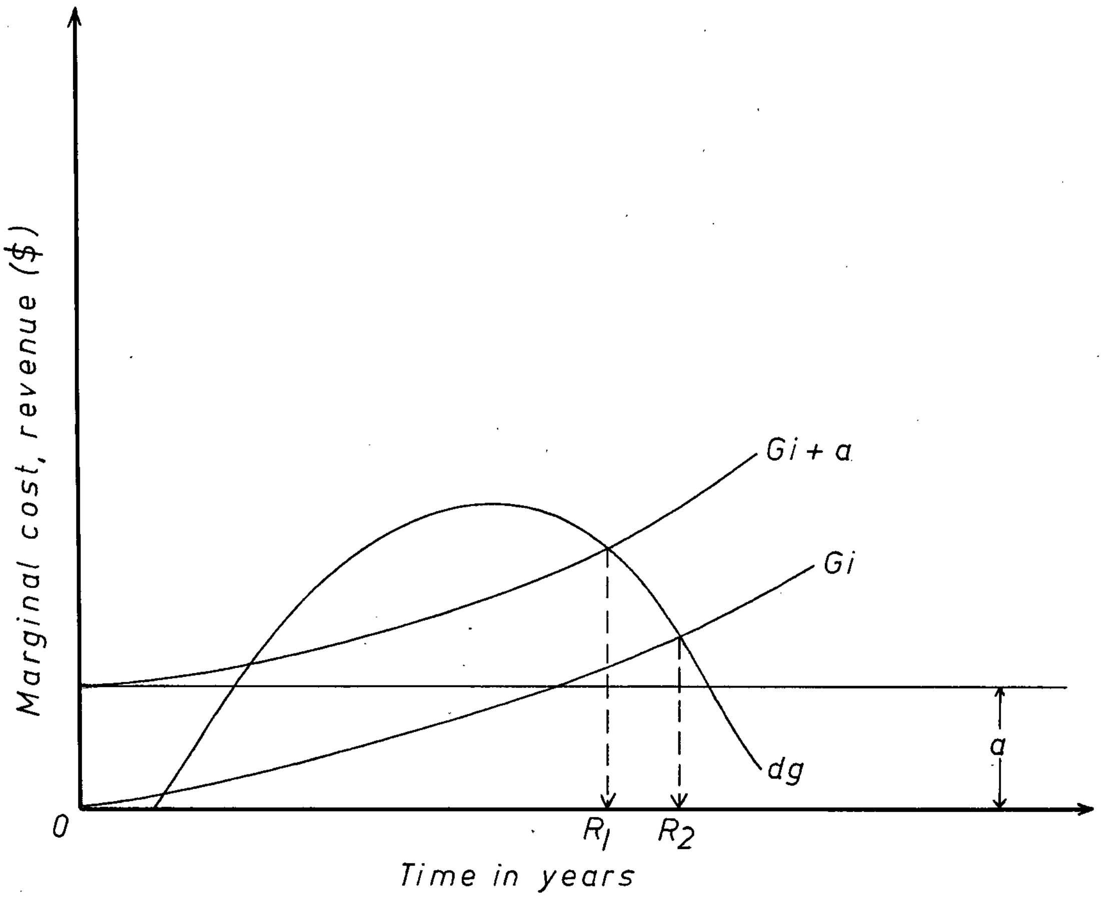
C. Rotation of financial maturity - This criterion (Duerr, 1960) varies from the Faustmann in as much as the culmination of the rotation occurs at the point where the marginal value growth per acre of the regulated growing stock expressed as a percentage value of the growing stock, is equal to the specified interest rate desired. In other words dg/G = i, where:

dg = the marginal value growth of the stand

G = capital value of the stand

i = cost of capital (specified discount rate).

FIGURE 12: Relationship of the optimum rotation length to marginal cost and revenue functions(1)



(1) After Haley (1966) and Pearse (1967)

This point is illustrated in Figure 12 by R_2. It is noted that a, the amortized value of the yearly site rent is excluded from the graph where this criterion is used. But Dobie (1966) found that Duerr's growth approach resulted in rotations for one study four years shorter than those determined using the Faustmann criterion. Dobie's data applied to an 86 year Douglas Fir stand which was processed for lumber. The interest rate used was three percent.

It is not safe to ignore the opportunity cost of land without first investigating the nature of the stand's value growth function (Haley, 1966).

3. Discussion and Summary

Time preference criteria are superior to zero interest forms because they weight costs and returns over time. They can also accommodate margins for uncertainty and risk. In general increases in interest rates, logging cost reductions and improved market prices reduce financial rotation lengths. Commercial thinnings have the opposite effect (Haley, 1964).

In spite of these advantages zero time preference criteria are used frequently because of lack of faith in future predictions of market conditions, value growth and political conditions. Different organizations utilize different criteria, depending upon the social behaviour exhibited by each one. It can be said that the criteria making use of income or revenue alone are useless as measurements of capital efficiency. The payback period is more often used for investment decisions within departments rather than at the top level of the firm or other agency. This infers of course that the financial rotation influences the whole financial structure of an enterprise rather than one of its parts. This leaves the accounting rate of return (single year) as a zero time preference criterion with possible short-run application to an enterprise.

Further reference is made to the financial criteria determining the rotation lengths of British Columbian forests in the following chapters.

CHAPTER VI

IMPLICATIONS OF ORGANIZATIONAL BEHAVIOUR

In the British Columbia forests 93 percent of the land is owned by the crown. Industry performs the role of contractors to the landlord's agent, the B.C. Forest Service. In order to attract long-term investment associated with economic security over 86 million acres of the productive forest area (118 million acres - 1957 inventory, B.C. Forest Service, 1958) have been placed under sustained yield forest management (B.C. Forest Service, 1967). On ten million of those acres under sustained yield management harvesting contracts are merely parts of larger, renewable licences (tree farm licences) to manage the land for timber production generally, although, public pressure for recreational use of some lands is expected to change this emphasis somewhat.

The purpose of this Chapter is to show that the formal financial criteria reviewed relate poorly to practices of two of the organizations discussed. The first is a typical tree farm licencee in the form of an integrated forest products company and the second is the B.C. Forest Service.

1. A Forest Products Company as a Tree Farm Licencee

A. Factors negating the use of 'time' preference criteria

The formal goal of the private company is usually to survive in the business for which it is designed. To do this it has to earn a return on invested capital for the investors concerned. In the case of the largest forest products company in British Columbia, MacMillan Bloedel Limited, this return is approximately twelve percent, net, after taxes.

The financial criteria used to determine such rates of return are affected by three characteristics which determine organizational behaviour in this direction. The first relates to the land tenure; the second to the uncertainty exhibited in attempting predictions of rotation determination eighty years or more into the future; and the third to future political changes which may jeopardize the chance of obtaining a return on capital invested.

Since so much of this land is publicly owned and under sustained yield management, companies cannot buy land for expansion purposes, nor can they invest in long term forest management practices on public land with a guarantee of the right to the final harvest. They do operate under the guarantees of a twenty-one year renewable tree farm licence to some extent. This means the company usually invests in plant, equipment and machinery necessary for timber extraction and processing, rather than in land and growing stock.

Next, the problem of forecasting growth and yield, costs and market prices, eighty years into the future to fit the requirements of the financial criteria reviewed has yet to be overcome. Uncertainty in investment decision-making in forest management weakens the use of time preference criteria (Walters, 1965).

Once more uncertainty of the future is re-inforced with the possibility of future changes in the political sphere. Provincialization of industry by expropriation, war and other unpredictable factors affect long-term investment. In fact, two of British Columbia's newest pulp mill projects are planned so that they repay the investors within twenty years of starting up.

Having indicated some weaknesses in the application of time preference criteria an attempt is made next to investigate actual practice.

B. Description of criteria used in budgeting, particularly in the forestry cost centre - Within an integrated forest products company, investment (or re-investment) capital is allocated by budgetting funds for a number of different divisions. Again, the division budgets are segregated into the budgets for a number of cost centres. A log supply division (or a company whose only role is to produce logs) contains a forestry cost centre which competes with a number of others (mechanical, administration, transportation, to name some) for the funds available.

These budgets represent the expected expenditures for a pre-determined period of time and are allocated per unit of production anticipated. In the case of forestry the forester responsible forecasts his expenditures in the form of reforestation, inventory, forest protection, forest research and other tasks (Wright, 1963). If he has planned for a number of extraordinary expenditures in addition to his normal operations the funds for these may have come from the cancellation of other projects or from unanticipated earnings.

The manager of the enterprise controls the allocation of funds. His criteria are often merely to place funds where the payback period is minimum. A mechanical superintendent who has requested a new machine, which will lower the mechanical expense by ten cents per unit of production, will receive more support from the manager, as compared to the forester's request for ten men to use for spacing or thinning project. The latter expenditure under the existing accounting practice can only increase the total production cost.

The manager realizes that his forestry costs are of two kinds: those that he has to incur to stay in business, and those that he incurs to obtain a higher annual cut. The first type is represented by forest protection and reforestation costs; the second by those costs which enhance m.a.i. values through redistribution of total growth amongst fewer trees, fertilization and other techniques.

It is these latter expenditures which require the use of certain criteria on the manager's part. The time preference criteria have as their objectives the maximizing of a return to investment capital through the choice of a particular rotation length. The manager's criterion has the same objective but the means he uses are not the same. By increasing the m.a.i. he increases the sustained yield capacity of the fixed factor land.[10]

But the manager's next step in deciding whether or not to invest funds to promote enhanced m.a.i. is to revert to his cost statements to determine the effect of the increased cut on his total costs. For it must be recognized that the costs for which the manager is responsible are either 'fixed' or 'variable'[11] and are expressed separately in dollars per unit of production. By increasing the annual cut noticeably through the application of moderately expensive forestry techniques the manager may find that his total cost per unit

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[10]Allowable annual cut = $\frac{\text{Mature Vol.}}{R}$ + m.a.i. x acres (U.B.C. Forestry Handbook, 1959)

[11]Fixed costs are those that continue even if the operation shuts down for a short length of time: depreciation on plant and equipment, salaries, maintenance expenses.

of production has decreased. Through the accounting rate of return criterion he will approve the forester's expenditure. The following hypothetical example is used to indicate how an increased annual cut may improve capital efficiency.

Given: based on a normal year ---

Annual cut = 100 MM fbm/year at a cost of \$55/M fbm

Selling price averages . . . . \$62/M fbm

Gross profit before taxes: \$62-\$55 = \$7 (100,000 M fbm)

= \$700,000

Deduct taxes (50% of gross profit)

Net profit after taxes = \$350,000

Given \$6,200,000 gross revenue for the year

Produces a rate of return of 5.6% (net)

Proposed for the following year by the forester:

By adding \$2/M fbm to the forestry budget and \$150,000 to the fixed costs, 15 MM fbm can be added to the original annual cut of 100 MM fbm

Proposed annual cut	=	115 MM fbm
Given: selling price	=	\$62/M fbm
fixed cost	=	\$3,150,000..\$27.31 M fbm
variable cost	=	\$3,105,000..\$27.00 M fbm
Total cost proposed	=	\$6,255,000..\$54.31 M fbm
Gross revenue (62)(115,000)	-	\$7,300,000
Gross profit before taxes	=	\$1,045,000

less 50% for taxes = $522,500

∴ net profit after taxes = $522,500

or 7.2% return on investment.

Through the manipulation of Hanzlik's formula the increased m.a.i. in the immature portion of the inventory is logged today in the form of additional mature or overmature volumes since the Provincial government has a policy which dictates that overmature forests be cut first. In this sense the rotation is shortened because of an increased yearly cut of old growth timber.

In the hypothetical example the manager has reduced the costs within his control from $55/M fbm to $54.31/M fbm by increasing the annual cut on the tree farm licence.

The expenditures in the forestry cost centre are treated as a charge against the production for the period and are matched against other variable unit costs. Extra funds will tend to reach the forestry cost centre if this increases net annual income, and increases the accounting rate of return (single year) on investment. There are two other reasons for assigning additional funds to the forestry cost centre.

The first is in the case of a company which is having trouble finding sufficient raw materials for its converting plants. The criterion for increased funds as costs to forestry may be made to obtain more wood at almost any cost. Lastly, the allocation of funds to the forestry cost centre may be justified on the basis that it is still cheaper to supply oneself rather than obtain it at a higher cost on the open market.

This completes an examination of the forest investment criteria used by a tree farm licence holder.

2. The British Columbia Forest Service

As described in Chapter II the B.C. Forest Service has held consistently to the culmination of m.a.i. criterion of rotation length. Having such a large responsibility it tends to be a cautious, conservative organization (Haley, 1966).

The B.C. Forest Service subscribes to the criterion which maximizes net annual growth, undiscounted (Haley, 1966). This means that the investments made by tree farm licencees to enhance merchantable m.a.i. production are not recognized by the B.C. Forest Service as having a future value either. Certain forestry costs incurred by the private sector are allowed in stumpage appraisals (thus reducing the minimum stumpage by twenty-five cents per C cf). But these are considered by the B.C. Forest Service to be more a loss of present revenue than an investment with the probability of future returns.

3. Summary and Conclusions

A review of various financial criteria has shown that they are either zero time preference or time preference criteria. To the economist searching for tools with which to analyse the behaviour of a particular industry or public resource agency the time preference criteria have some use. In his role of social observer the economist needs time preference criteria as well to point out the various alternatives for the decisions which governments must make from time to time.

In the case of the tree farm licencee the Faustmann approach to rotation determination for instance is unrealistic. The stability of one hundred years ago is not in keeping with the dynamic conditions of today. These criteria which maximize a return to public land are not realistic in the British Columbian situation from the viewpoint of the private firm.

The industrial criteria in regard to forest management in British Columbia govern the levels of m.a.i. rather than the length of rotation. At some future time the correlation between enhanced m.a.i. values and reduced rotations may become evident. This will not occur though until the B.C. Forest Service is convinced of the profitability of logging younger stands of a reduced marginal size. In the meantime the criterion of maximized mean annual growth, undiscounted, determines rotation length, regardless of tree size.

It is concluded then, that the behaviour of both private company and the B.C. Forest Service precludes the use of the traditional financial criteria for the determination of rotations. The environment no longer supports the forecasting of investment returns in terms of eighty to one hundred years without some regard to changing utilization and means for periodic review of indicated rotation lengths.

CHAPTER VII

THE ECONOMIC IMPLICATIONS OF SOME PHYSICAL ELEMENTS OF ROTATION DETERMINATION

To this point both physical and financial criteria for the determination of rotations for B.C. forests have been considered. Of the former, the culmination of m.a.i. criterion has been adopted by both public agency and private enterprise. The latter have received no formal support except by the economist in the role of social examiner, as stated previously. Furthermore, he is more satisfied with the time preference criteria discussed than with zero interest forms such as the payback period.

This division of outlook between the forest manager and the economist, because of the divergence of perceived goals, may have outcomes which are virtually the same. By using the average stand diameter ($\bar{D}$) as well as the yield per acre at the age corresponding to the culmination of m.a.i. the forest manager's physical rotation length may compare well with the economist's financial counterpart.

The purpose of this Chapter is to indicate how $\bar{D}$ values determined for some B.C. Forest Service volume/age curves may well be used to approximate the rotation common to both physical and economic forms.

The use of $\bar{D}$ to indicate conversion returns and other accounting levels has been tested by Haley (1964), Dobie (1966) and Lee (1967), amongst others. As a qualifier of merchantability, $\bar{D}$ estimates associated with expected yields per acre may cause the indicated rotation to change somewhat.

To illustrate the relationship of $\bar{D}$ to expected yield and m.a.i. figures 13, 14 and 15 are presented for Douglas Fir, Spruce and Lodgepole Pine types, site index 100. It should be noted that the indicated rotations are shown as the averages $\pm$ one standard deviation from them. This range of rotation values, thirty-six years in the case of Douglas Fir types, may well incorporate values derived by time preference techniques. From these figures it is seen that the comparable figures for Spruce and Lodgepole Pine types are twenty-six years and twelve years, respectively.

Having indicated the relationship of m.a.i. to $\bar{D}$, the next step is to assign value and cost functions to the various $\bar{D}$ levels. It is then possible to manipulate the conversion returns (selling price - operating cost) by deferring the harvest, or by operating on short rotations. Using Figure 15 as an example, Spruce grown for pulp may be logged every sixty-nine years, for this site index.

Given the size of the marginal tree, it becomes possible to indicate the profitability of each logging operation required

FIGURE 13: M.A.I., yield and possible $\bar{D}$ relationship for D. fir, site index 100, for trees 7.1 inches D.B.H. and larger.

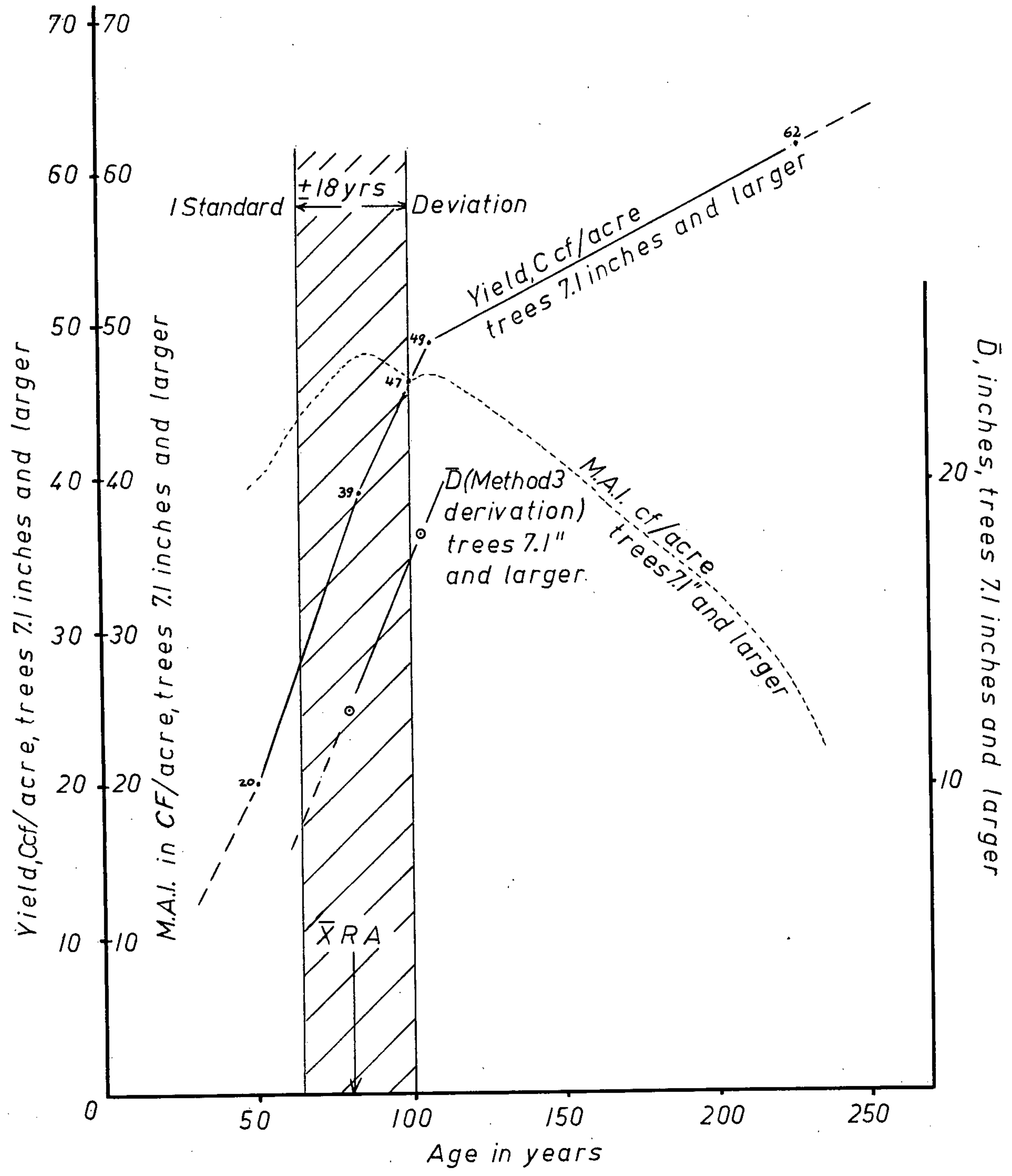


FIGURE 14: M.A.I., yield and possible D relationship for spruce types, site index 100, for trees 7.1 inches D.B.H. and larger.

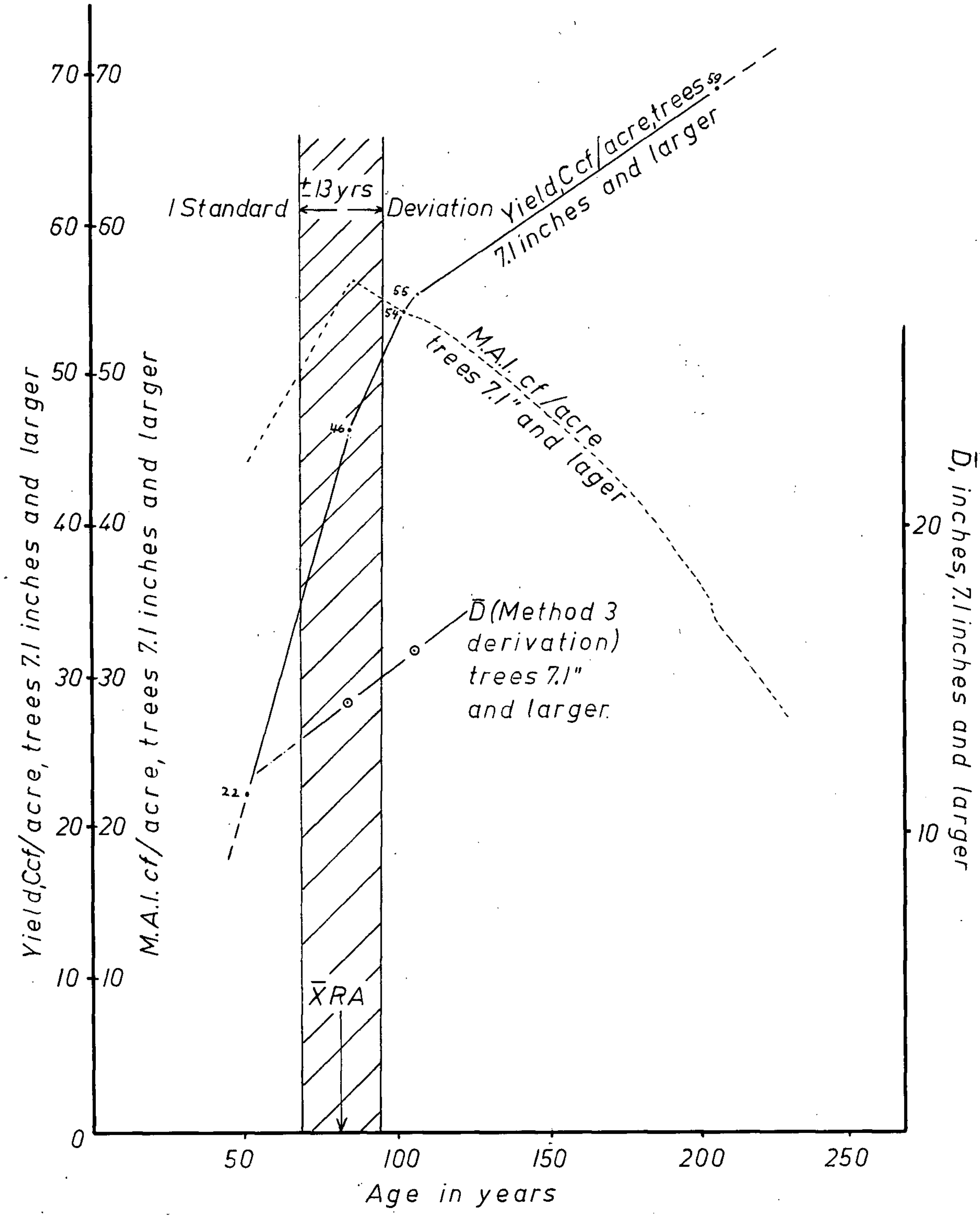
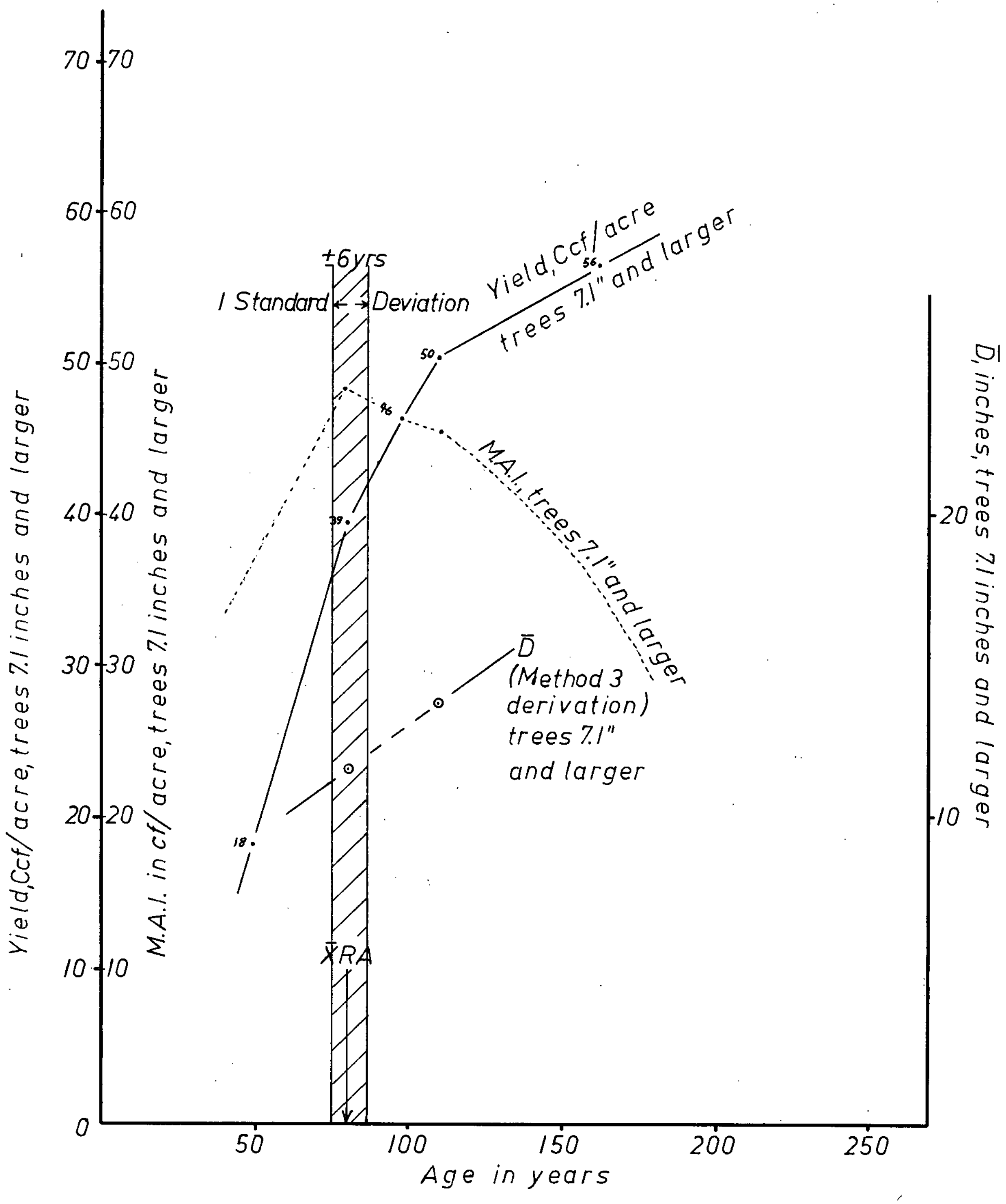


FIGURE 15: M.A.I., yield and possible $\bar{D}$ relationship for lodge pole pine types, site index 100, for tree 7.1 inches D.B.H. and larger.



to remove annual harvests. These, in turn, may be accelerated or retarded, depending upon the products desired and site index represented.

Haley's (1964) financial rotation for Douglas Fir, site index 100 ($25 fixed cost and $1/annum maintenance charge, $20/acre/annum establishment cost) at 3 percent interest rate is ninety years. This is eight years more than the volume/age curve value indicated in Figure 13. Even if the interest rate was raised to 7 percent with a subsequent reduction in the financial rotation of thirty years, this still remains within the limits of the physical rotation for Douglas Fir.

Smith (1968) stated: "A valuable compromise position has been adopted recently by the U.S. Forest Service. Rotation length in National Forests is set now by the number of years expected to be required to grow trees of the species, size and quality likely to be needed in the future."

The conclusion, therefore, is that there is indeed an economic implication in the length of the physical rotation. Furthermore, a physical rotation properly prescribed by a $\bar{D}$ value and indication of the size of the range of values about it, may be said to roughly approximate and often include the financial rotation. This means that as financial conditions in manufacturing and marketing change, so shall the size of the economically marginal tree change. This, in turn, causes a change to be made in the rotation length.

CHAPTER VIII

GENERAL CONCLUSIONS AND RECOMMENDATIONS

1. General Conclusions

This analysis of some physical and economic criteria determining rotations in British Columbia produced general conclusions:

A) The B.C. Forest Service volume/age curves have some use in forest management because they describe average yields of natural, unmanaged stands. They can be sorted and summarized to provide data on rotation age yield. When information from these curves is compared with results from estimates at variable densities and full stocking, managers will be able to budget more effectively for those techniques necessary to produce merchantable yields in the fastest time;

B) The forest manager using the accounting rate of return (single year) investment criterion and the economist using time preference criteria both have the same objective, namely the most efficient use of capital. This objective is more likely to be gained by the managers by planning in a series of steps toward desired goals of up to twenty years each.

The economist's time preference may span a single rotation.

2. Recommendations

At the conclusion of this study two recommendations are made:

A) The rotation criterion adopted for British Columbia should be a blend of economic and physical criteria. In addition to equating rotation lengths with site index lines the Forest Service of the Province should extend its most recent work by qualifying the yields expected with a reference to the size of the economically marginal tree expected. By ranking rotations according to various levels of merchantability officers of the Service will be more able to encourage policies designed to use the Provincial forest resource better and more completely. This implies uses in addition to harvesting of timber.

B) In order to undertake the first recommendation presented it is suggested that the Forest Service continue its excellent assessment of rotation determination through the use of volume/age curves. Analyses to indicate growth behaviour at full stocking and variable stand densities would enable all forest managers to adopt 'standards' of merchantable yields, according to various utilization limits, for which to strive.

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APPENDIX I

BRITISH COLUMBIA FOREST SERVICE VOLUME/AGE CURVES: SUMMARIES OF CERTAIN VARIABLES BY GROWTH TYPE, FOR 9 INVENTORY ZONES WITHIN 4 SITE CLASSES - VOLUMES IN C cf OR cf/ACRE, CLOSE STANDARD OF UTILIZATION, NET FOR DECAY ONLY.

DESCRIPTION OF VARIABLES:

$\bar{X}$RA	:	Average rotation in years, 7.1"D+ or 9.1"D+; at culmination of M.A.I;
$\bar{X}$YA	:	yield, C cf/acre corresponding to RA;
$\bar{X}$RB	:	average rotation in years, 11.1"D+ or 13.1"D+, at culmination of M.A.I;
$\bar{X}$YB	:	yield, C cf/acre corresponding to RB;
$\bar{X}$RC	:	average rotation in years, 7.1"D+ or 11.1"D+, at culmination of volume growth;
$\bar{X}$YC	:	yield, C cf/acre corresponding to RC;
AVE SITE	:	average site index for class;
$\bar{X}$YA^{1}	:	portion of volume at RA attributable to 11.1"D+ or 13.1"D+;
$\bar{X}$YB^{1}	:	portion of volume at RB attributable to 7.1"D+ or 9.1"D+;
$\bar{X}$VP50	:	yield, C cf/acre 7.1"D+ or 9.1"D+, at age 50;
$\bar{X}$VP100	:	yield, C cf/acre 7.1"D+ or 9.1"D+ at age 100;
M.A.I.	:	yield, cf/acre 7.1"D+ or 9.1"D+ at RA years;
P.A.I.	:	(or GRPT), periodic annual increment determined from the formula: GRPT = $\frac{(\bar{X}VP100 - \bar{X}VP50)100}{50}$

GROWTH TYPE	SITE INDEX CLASS	ZONE NO.	NO. CURVES IN CLASS	NO. PLOTS TO R_A	TOTAL NO. PLOTS	YIELDS IN Ccf/ACRE, ROTATIONS IN YEARS ± STANDARD DEVIATIONS — MATURE 7.1"D. OR 9.1"D+ $\bar{X}Y_A$	$\bar{X}R_A$	MATURE 11.1"D+ OR 13.1"D+ $\bar{X}Y_B$	$\bar{X}R_B$	OVERMATURE 7.1"D+ OR 9.1"D+ $\bar{X}Y_C$	$\bar{X}R_C$	AVE. SITE INDEX ± SD	SUPPLEMENTARY YIELDS Ccf/ACRE — 11.1"D+ OR 13.1"D+ $\bar{X}Y_A'$	7.1"D+ OR 9.1"D+ $\bar{X}Y_B'$	7.1"D+ OR 9.1"D+ VP_{50}	VP_{100}	MAI cf/ACRE AT R_A	PAI % FOR 50 TO 100 YRS	AVE NO. PLOTS TO R_A ± SD	AVE NO. PLOTS TOTAL ± SD
1	1	2	1	138	155	106	72	113	86	195	330	160	90	124	62	138	149	1.1	138	155
1	1	4	1	5	34	29	50	30	71	53	250	100	18	39	29	46	58	.7	5	34
1	1	5	2	46	105	52 9	92 4	53 10	106 6	78 20	211 27	100 0	44 8	58 9	15 1	56 11	56 12	1.5 .1	23 16	52 38
1	1	6	1	51	121	30	58	36	91	50	185	100	20	50	26	47	52	.9	51	121
1	2	2	1	149	339	62	63	66	89	112	330	120	43	81	47	86	98	.9	149	339
1	2	4	1	29	96	29	85	27	108	56	290	80	20	35	14	34	34	1.2	29	96
1	2	5	3	92	421	28 9	109 25	27 8	129 20	40 11	251 46	80 0	22 9	32 9	9 7	25 11	26 9	1.4 .3	31 21	140 162
1	2	6	1	97	202	22	81	22	117	30	155	80	14	27	12	26	27	1.1	97	202
1	3	2	1	181	316	32	79	43	141	68	320	80	18	50	19	40	40	1.0	181	316
1	3	5	3	213	804	19 5	122 10	18 4	149 10	26 4	274 28	65 0	14 4	21 4	3 1	14 3	15 4	1.6 .2	71 81	268 281
1	3	6	1	115	200	17	125	14	140	20	180	65	12	18	4	12	14	1.3	115	200
1	4	1	1	26	46	22	95	22	138	36	270	65	13	30	9	24	23	1.2	26	46
1	4	2	1	0	0	24	140	22	190	24	310	40	14	30	5	16	17	1.4	0	0
1	4	4	1	0	0	12	152	12	203	18	250	30	7	16	2	8	8	1.5	0	0
1	4	5	1	0	0	7	150	7	180	10	250	30	4	8	1	4	5	1.5	0	0
1	4	6	1	0	0	8	146	6	170	10	220	30	5	9	0	4	6	2.0	0	0
2	1	2	2	26	118	85 4	61 8	96 12	79 11	182 46	320 0	160 0	73 7	107 10	70 5	128 4	140 12	.9 .1	13 10	59 57
2	1	4	4	36	188	38 5	80 11	39 5	106 9	62 6	243 54	100 0	28 6	48 4	21 2	46 3	47 3	1.1 .1	9 6	47 30
2	1	5	5	32	148	39 13	81 12	38 11	99 10	60 19	216 58	100 0	29 8	47 15	18 6	47 13	49 12	1.2 .2	8 4	30 15
2	1	6	11	267	592	40 4	82 18	41 5	108 19	66 10	222 44	97 9	28 5	52 5	22 6	48 7	51 8	1.1 .2	24 20	54 32
2	2	2	5	105	1177	71 10	92 28	72 11	108 27	124 16	308 13	118 4	58 12	82 9	33 16	76 15	81 19	1.2 .3	21 17	235 183
2	2	4	6	96	285	28 7	87 13	27 7	118 10	42 8	227 51	80 0	19 7	36 8	12 2	31 6	32 5	1.2 .2	16 12	47 27
2	2	5	8	121	311	28 8	111 19	26 6	134 18	39 14	228 45	80 0	21 5	32 9	7 2	25 7	26 7	1.4 .1	15 6	39 18
2	2	6	11	346	707	30 9	95 24	29 8	119 26	46 13	214 58	80 0	21 7	37 10	12 5	31 7	32 8	1.3 .2	32 21	64 42
2	3	2	5	295	680	44 6	106 11	46 6	145 9	72 9	316 15	80 0	32 7	56 4	16 1	40 3	41 4	1.2 .1	57 45	136 103
2	3	4	3	43	56	22 11	111 10	19 10	132 8	28 13	200 35	63 3	14 8	25 13	6 2	19 8	20 9	1.3 .1	14 7	19 7
2	3	5	8	136	292	19 9	115 10	16 6	139 9	26 15	222 54	65 0	12 5	22 11	4 2	17 6	16 7	1.6 .2	17 12	37 23
2	3	6	9	226	393	21 4	108 19	19 4	130 18	30 8	197 80	65 0	14 3	25 6	7 3	19 5	20 5	1.4 .2	25	44
2	4	2	1	0	0	27	144	24	190	42	300	40	17	33	5	18	19	1.4	0	0
2	4	4	1	0	0	9	130	6	152	11	195	30	4	10	1	6	7	1.7	0	0
2	4	5	1	0	0	11	140	9	182	17	270	30	6	13	1	7	8	1.7	0	0
2	4	6	1	0	0	11	150	8	170	17	270	30	6	12	2	7	7	1.4	0	0
3	1	4	2	30	116	38 0	78 13	37 2	99 17	60 5	208 46	100 0	27 1	46 0	21 4	48 5	49 8	1.1 .1	15 6	58 32
3	1	5	1	22	30	36	100	36	118	50	223	100	29	42	12	36	36	1.3	22	30
3	1	6	4	108	193	31 14	97 35	29 13	113 32	42 23	224 41	100 0	23 11	37 16	13 8	33 15	35 15	1.3 .4	27 22	48 33
3	2	4	2	166	221	35 2	102 0	31 4	126 3	49 1	258 60	80 0	24 3	42 4	12 3	34 3	34 2	1.3 .1	83 24	111 28
3	2	5	3	69	214	20 1	93 6	17 1	114 9	27 1	199 22	80 0	13 1	23 1	6 2	21 1	21 2	1.4 .2	23 27	71 54
3	2	6	3	130	232	32 22	82 23	27 20	109 25	32 9	212 33	80 0	14 7	29 10	11 3	33 16	37 16	1.2 .4	43 54	77 86
3	3	4	2	64	76	30 11	113 28	27 13	147 35	46 17	285 7	65 0	20 9	37 13	6 3	26 2	26 4	1.5 .2	32 6	38 7
3	3	5	3	109	454	13 3	96 15	11 3	129 29	19 4	231 61	65 0	7 1	15 4	4 1	13 2	13 2	1.3 .1	36 20	151 92
3	3	6	4	158	279	16 7	112 36	14 6	131 32	23 10	233 22	65 0	11 5	17 7	5 4	14 8	15 7	1.4 .3	40 43	70 77
3	4	4	1	0	0	12	133	8	152	17	280	30	6	14	2	8	9	1.5	0	0
3	4	5	1	0	0	4	106	3	132	6	170	30	2	5	1	2	4	1.0	0	0
3	4	6	1	0	0	6	136	4	150	8	260	30	4	6	1	4	4	1.5	0	0
4	1	6	5	108	333	39 10	79 18	40 9	109 18	64 8	259 29	100 0	26 8	50 10	21 4	47 4	49 5	1.1 .2	22 22	67 72
4	2	6	5	189	404	31 4	103 26	29 5	131 27	44 6	210 27	80 0	22 5	39 7	11 3	30 5	31 5	1.3 .2	38 22	81 70
4	3	6	4	123	232	27 4	106 22	23 5	131 27	37 10	223 59	65 0	18 4	32 5	8 3	30 14	26 3	1.5 .2	31 28	58 71
4	4	6	1	0	0	10	120	8	162	17	280	30	5	14	2	8	8	1.5	0	0
5	1	2	1	3	75	95	88	96	97	158	320	150	86	109	46	107	108	1.1	3	75
5	1	4	2	7	35	42 1	81 17	42	96 24	60 6	166 8	110 0	35 2	48 1	22 8	50 8	52 12	1.2 .2	4 0	18 9
6	1	6	2	28	144	55 7	100 20	57 4	118 12	94 6	298 11	110 0	47 10	64 3	19 6	55 4	56 4	1.3 .12	14 14	72 62
5	2	1	2	8	106	66 14	94 12	71 13	99 7	115 7	330 14	110 0	48 14	85 3	40 3	84 9	89 5	1.0 .2	4 4	53 16
5	2	2	3	99	1286	71 13	107 15	74 14	126 20	118 12	290 30	110 0	62 12	83 15	24 3	67 1	66 3	1.3 .1	33 32	429 416
5	2	4	2	13	97	40 3	105 9	40 2	121 11	55 1	225 35	90 0	33 1	45 3	10 2	38 1	38 1	1.5 .1	7 6	49 20
5	2	6	3	68	274	54 10	122 17	60 7	153 21	87 11	286 9	90 0	46 11	66 6	14 4	44 5	45 6	1.3 .2	23 27	91 108
5	3	1	2	6	276	38 3	99 1	38 2	123 6	77 1	330 14	70 0	30 0	46 4	16 1	38 3	38 2	1.2 0	3 1	138 105
5	3	2	3	72	1181	49 8	113 7	49 9	139 8	74 17	272 58	70 0	37 6	62 16	12 2	42 6	44 6	1.4 .2	24 28	394 507
5	3	4	2	7	75	30 0	108 19	28 1	129 20	40 0	210 63	60 0	22 1	35 1	8 3	28 6	28 5	1.4 .1	4 4	38 22
5	3	6	2	78	202	43 1	157 11	42 0	175 10	61 10	273 24	60 0	37 1	48 1	4 1	24 2	27 2	1.7 .2	39 42	101 61
5	4	1	1	0	0	21	137	18	170	33	290	40	14	26	4	15	15	1.5	0	0
5	4	2	1	0	0	28	197	22	181	40	300	40	18	32	2	16	19	1.7	0	0
5	4	4	1	0	0	14	151	12	155	20	280	30	9	16	2	10	11	1.6	0	0
5	4	6	1	0	0	26	211	21	228	29	260	30	20	28	1	7	12	1.7	0	0

GROWTH TYPE	SITE INDEX CLASS	ZONE NO.	NO. CURVES IN CLASS	NO. PLOTS TO R_A	TOTAL NO. PLOTS	YIELDS IN Ccf/ACRE, ROTATIONS IN YEARS ± STANDARD DEVIATIONS						AVE. SITE INDEX ± SD	SUPPLEMENTARY YIELDS Ccf/ACRE				MAI cf/ACRE AT R_A	PAI % FOR 50 TO 100 YRS	AVE NO. PLOT TO R_A ± SD	AVE NO. PLOTS TOTAL ± SD
						MATURE 7.1"D+ OR 9.1"D+		11.1"D+ OR 13.1"D+		OVERMATURE 7.1"D+ OR 9.1"D+			11.1"D+ OR 13.1"D+	7.1"D+ OR 9.1"D+	7.1"D+ OR 9.1"D+					
						$\bar{X}Y_A$	$\bar{X}R_A$	$\bar{X}Y_B$	$\bar{X}R_B$	$\bar{X}Y_C$	$\bar{X}R_C$		$\bar{X}Y_A'$	$\bar{X}Y_B'$	VP_{50}	VP_{100}				
6	1	2	1	22	106	80	64	85	81	142	226	150	66	96	61	113	125	.9	22	105
6	1	3	1	6	26	56	91	55	105	84	225	110	46	64	22	61	62	1.3	6	26
6	1	6	1	5	16	36	64	38	87	66	300	110	25	46	26	50	56	1.0	5	16
6	2	2	1	54	260	57	69	60	88	106	310	110	42	74	40	78	83	1.0	54	260
6	2	1	1	2	84	59	85	60	108	100	320	110	44	70	28	68	69	1.2	2	84
6	2	3	1	20	110	56	94	60	139	83	250	90	34	74	23	58	60	1.2	20	110
6	2	6	2	20	90	45 1	114 20	46 3	139 20	62 0	295 7	90 0	35 0	52 4	6 3	39 10	40 8	1.7 .1	10 1	45 26
6	3	1	1	4	41	35	117	36	159	56	320	70	20	46	12	32	30	1.2	4	41
6	3	2	1	59	109	40	120	39	155	62	320	70	28	50	13	34	33	1.2	59	109
6	3	3	1	19	174	46	112	49	172	75	310	60	26	62	10	40	41	1.5	19	174
6	3	4	1	3	19	29	107	26	125	35	165	60	21	32	4	26	27	1.7	3	19
6	3	6	1	11	53	41	122	42	147	53	203	60	33	48	10	32	34	1.4	11	53
6	4	1	1	0	0	20	153	18	199	31	300	40	12	25	2	12	13	1.7	0	0
6	4	2	1	0	0	24	153	22	202	34	310	40	14	30	4	14	16	1.4	0	0
6	4	3	1	0	0	22	163	26	255	36	300	40	13	34	7	12	14	.8	0	0
6	4	4	1	0	0	14	140	10	161	16	200	30	8	16	1	8	10	1.7	0	0
6	4	6	1	0	0	22	166	18	187	28	270	30	16	24	2	10	13	1.6	0	0
7	1	1	2	15	56	91 10	66 5	90 8	80 11	150 32	202 96	150 0	71 13	108 8	67 16	122 18	140 26	.9 .1	8 5	28 1
7	1	2	4	83	333	72 11	68 9	80 11	88 6	142 8	291 64	150 0	62 6	91 13	51 11	100 17	108 21	1.0 .1	21 20	83 104
7	1	3	2	9	119	65 1	95 9	66 4	108 9	95 1	252 25	110 0	56 3	73 1	26 3	68 4	69 6	1.2 .0	4 4	60 5
7	1	6	5	43	181	50 8	101 17	55 12	124 18	84 11	260 20	110 0	43 9	60 11	19 4	47 8	50 4	1.2 .1	9 5	36 14
7	2	1	4	19	427	63 10	75 7	69 6	104 12	114 17	318 17	110 0	45 12	82 7	36 5	80 11	65 14	1.0 0	5 4	107 105
7	2	2	4	274	1148	72 11	103 12	75 9	123 12	115 7	300 27	110 0	61 11	84 10	26 4	69 5	70 6	1.2 1	69 76	368 62
7	2	3	2	44	321	56 3	98 11	63 1	146 4	90 3	320 0	90 0	36 9	74 1	22 3	56 3	57 3	1.2 .1	22 10	160 86
7	2	4	2	15	93	40 4	98 4	42 9	121 16	64 12	255 50	90 0	31 4	49 11	16 3	42 5	41 5	1.2 0	8 4	46 44
7	2	6	9	152	718	48 7	116 13	50 8	137 17	73 11	293 13	90 0	39 7	56 8	12 3	40 3	41 3	1.4 .1	17 10	80 44
7	3	1	3	13	270	41 13	88 8	44 17	130 16	69 22	310 10	70 0	25 10	55 17	18 4	46 12	46 12	1.2 .1	4 4	93 97
7	3	2	5	135	1159	59 9	140 26	57 8	161 17	82 8	283 47	68 4	49 12	67 7	11 3	38 5	42 3	1.5 .1	27 22	232 262
7	3	3	2	25	497	47 1	119 4	50 1	166 1	76 1	305 7	60 0	29 4	60 1	12 1	39 0	40 0	1.4 .2	12 12	248 75
7	3	4	2	18	239	34 6	106 22	33 7	129 18	50 12	240 57	60 0	26 9	39 6	8 6	31 1	32 1	1.5 .3	9 8	120 49
7	3	6	7	129	440	42 7	133 20	40 7	152 19	56 9	242 45	60 0	34 8	47 6	7 1	28 4	31 3	1.5 .1	18 11	63 58
7	4	1	1	0	0	26	123	24	166	38	300	40	16	32	6	20	21	1.4	0	0
7	4	2	1	0	0	30	143	25	178	41	310	40	18	35	3	18	21	1.7	0	0
7	4	3	1	0	0	25	171	22	235	37	300	40	16	30	6	12	15	1.5	0	0
7	4	4	1	0	0	14	126	12	179	21	250	30	12	21	2	10	11	1.6	0	0
7	4	6	1	0	0	18	156	18	212	29	280	30	12	24	2	10	12	1.6	0	0
8	1	2	1	0	120	96	66	98	78	156	320	96	79	110	66	126	145	1.0	0	120
8	1	3	2	5	125	44	74	47	100	86	320	96	33	57	28	57	59	1.0	3	63
8	1	4	11	93	428	37 6	80 9	37 7	105 12	54 8	204 51	96 0	26 6	43 12	18 4	44 7	46 7	1.2 .1	8 8	39 23
8	1	5	2	10	54	63 1	106 12	61 1	119 13	86 4	234 9	96 0	54 0	69 1	16 4	58 8	60 8	1.4 0	5 1	27 3
8	1	6	8	43	310	37 7	75 9	37 6	98 12	57 7	214 40	96 0	26 7	45 0	21 3	46 7	49 8	1.1 .2	5	39 32
8	2	1	1	2	92	74	91	77	116	120	320	110	58	90	32	80	81	1.2	2	92
8	2	2	1	14	517	88	105	90	120	126	330	75	76	99	18	83	84	1.6	14	517
8	2	3	2	6	272	38 3	85 1	44 5	116 6	63 1	310 0	75 0	25 1	48 2	17 1	44 3	45 4	1.2 0	3 1	136 54
8	2	4	10	103	918	31 5	92 17	28 4	121 11	42 6	190 54	75 0	19 4	37 8	11 6	33 7	34 7	1.3 .4	10 7	92 83
8	2	5	3	22	163	38 0	123 26	41 4	154 38	63 5	260 61	75 0	31 7	51 6	9 5	35 15	32 6	1.5 .1	7 7	54 33
8	2	6	9	61	539	28 7	94 22	28 7	119 21	42 8	232 65	73 7	19 6	35 8	11 4	29 6	30 4	1.4 .3	7 10	62 71
8	2	9	1	8	37	17	99	13	148	24	156	75	7	22	6	17	17	1.3	8	37
8	3	1	1	0	39	62	119	62	143	86	320	70	42	62	12	43	44	1.4	0	39
8	3	2	2	23	266	56 13	126 13	56 6	167 13	90 6	315 7	62 12	38 17	68 8	11 6	40 1	44 6	1.4 .3	12 8	132 131
8	3	3	1	5	130	29	112	26	165	43	310	53	16	37	8	26	26	1.4	5	130
8	3	4	10	157	924	21 6	111 19	17 4	138 19	29 6	224 59	53 0	12 4	25 6	4 1	19 4	18 5	1.6 .2	16 20	92 115
8	3	5	2	22	108	36 0	136 23	28 3	167 5	46 2	242 2	53 0	21 4	42 3	4 2	23 7	27 4	1.6 .1	11 4	54 4
8	3	6	8	85	324	22 5	112 27	17 5	130 20	26 6	193 44	53 0	14 4	24 4	7 3	18 6	20 4	1.5 .4	11 16	40 60
8	4	1	1	0	0	30	165	26	197	40	300	40	20	34	2	14	18	1.7	0	0
8	4	2	1	0	0	32	155	28	192	45	300	40	20	38	4	18	21	1.6	0	0
8	4	3	1	0	0	14	126	10	167	18	300	40	6	16	2	10	11	1.6	0	0
8	4	4	1	0	0	10	142	6	185	14	250	30	5	12	1	6	7	1.7	0	0
8	4	5	1	0	0	14	193	10	215	17	260	30	9	16	1	5	8	1.6	0	0
8	4	6	1	0	0	10	145	6	159	14	270	30	5	10	1	6	7	1.7	0	0
9	1	4	2	33	621	43 4	83 1	42 5	93 9	59 4	172 11	96 0	34 3	50 5	18 0	51 4	52 4	1.3 .1	16	310
9	1	5	1	6	43	40	78	43	109	62	220	96	28	52	22	49	51	1.1	6	43
9	1	9	1	8	123	40	78	38	98	59	160	96	28	49	23	50	51	1.1	8	123

GROWTH TYPE	SITE INDEX CLASS	ZONE NO.	NO. CURVES IN CLASS	NO. PLOTS TO R_A	TOTAL NO. PLOTS	YIELDS IN Ccf/ACRE, ROTATIONS IN YEARS ± STANDARD DEVIATIONS: MATURE 7.1"D+ OR 9.1"D+ $\bar{X}Y_A$	$\bar{X}R_A$	MATURE 11.1"D+ OR 13.1"D+ $\bar{X}Y_B$	$\bar{X}R_B$	OVERMATURE 7.1"D+ OR 9.1"D+ $\bar{X}Y_C$	$\bar{X}R_C$	AVE. SITE INDEX ± SD	SUPPLEMENTARY YIELDS Ccf/ACRE: 11.1"D+ OR 13.1"D+ $\bar{X}Y_A'$	7.1"D+ OR 9.1"D+ $\bar{X}Y_B'$	7.1"D+ OR 9.1"D+ VP_{50}	VP_{100}	MAI cf/ACRE AT R_A	PAI % FOR 50 TO 100 YRS	AVE NO. PLOTS TO R_A ± SD	AVE NO. PLOTS TOTAL ± SD
9	2	4	2	30	354	32 5	96 16	30 4	126 1	44 2	204 16	75 0	20 8	39 1	10 6	33 1	33 1	1.4 .3	15 15	177 11
9	2	5	1	8	68	40	102	38	126	56	235	75	29	47	10	39	39	1.5	8	68
9	2	9	1	46	194	34	96	28	110	44	168	75	17	42	10	36	36	1.9	46	194
9	3	4	2	32	90	24 6	120 29	20 8	149 32	33 4	256 32	53 0	15 7	28 7	5 1	19 1	20 0	1.5 .1	16 1	45 6
9	3	5	1	2	42	26	107	25	175	44	300	53	10	37	8	25	24	1.9	2	42
9	3	9	1	103	192	20	132	14	179	30	310	53	10	26	2	14	16	1.7	103	192
9	4	4	1	0	0	8	130	6	158	12	290	30	4	10	1	6	6	1.7	0	0
9	4	6	1	0	0	16	193	11	209	19	290	30	10	17	0	4	8	2.0	0	0
9	4	9	1	0	0	8	152	6	203	14	300	30	4	10	0	4	5	2.0	0	0
10	1	3	2	20	81	46 6	81 13	48 6	108 11	68 3	182 4	96 0	35 7	57 4	25 3	56 1	67 2	1.1 .1	10 8	40 9
10	1	4	15	215	1584	40 4	82 9	39 6	106 16	67 6	180 41	97 4	28 4	49 5	19 3	48 5	50 6	1.2 .1	14 11	106 90
10	1	5	2	7	125	40 0	72 5	38 4	88 12	63 10	232 81	96 0	29 0	46 4	24 0	50 0	56 4	1.0 0	4 4	62 36
10	1	6	5	49	500	38 5	76 20	41 3	99 22	64 6	231 57	96 0	29 3	49 3	23 7	50 6	51 10	1.1 .2	10 8	100 69
10	1	9	1	32	117	44	92	40	110	58	170	96	32	50	13	47	48	1.4	32	117
10	2	2	2	18	234	77	112	78	120	126	310	110	67	88	22	70	70	1.4	9	117
10	2	3	1	4	15	34	73	32	103	62	185	75	20	44	20	43	47	1.1	4	15
10	2	4	14	151	1462	31 6	92 13	29 5	119 12	44 5	189 31	75 0	20 6	40 6	12 3	34 3	34 4	1.3 .2	11	104 95
10	2	5	4	26	218	31 6	93 17	24 6	119 19	46 9	220 47	75 0	18 3	37 8	12 4	32 4	33 4	1.3 .2	7	54 22
10	2	6	5	37	606	31 4	99 26	30 4	128 28	47 6	252 31	75 0	21 3	39 4	11 4	32 5	32 4	1.3 .2	74 6	121 85
10	2	9	2	32	156	34 14	92 23	20 8	126 16	45 13	180 7	64 16	18 9	41 13	11 4	35 7	36 6	1.3 .4	16 14	78 66
10	3	2	1	19	59	56	140	57	161	98	300	70	60	63	11	37	40	1.4	19	59
10	3	3	1	0	11	20	102	14	184	28	195	53	9	25	4	20	20	1.6	0	11
10	3	4	11	115	476	23 4	115 13	17 3	107 17	29 6	198 49	53 0	13 3	26 4	4 2	19 3	20 2	1.6 .2	10 10	43 41
10	3	5	3	17	143	24 3	119 19	16 2	138 18	33 6	208 56	63 0	16 5	58 40	4 1	20 6	21 4	1.8 .2	6 4	48 5
10	3	6	4	25	208	23 5	110 26	20 4	154 22	31 4	225 44	53 0	13 4	27 6	6 3	20 2	21 2	1.5 .2	6 4	52 28
10	3	9	2	58	166	25 3	136 3	16 1	151 8	28 8	205 7	53 0	14 2	28 2	2 1	16 1	18 2	1.7 .2	29 21	82 38
10	4	3	1	0	0	8	125	6	173	14	260	30	3	12	2	7	6	1.4	0	0
10	4	4	1	0	0	11	138	6	162	16	260	30	5	12	1	7	8	1.7	0	0
10	4	5	1	0	0	12	156	8	182	18	260	30	6	14	0	6	8	2.0	0	0
10	4	6	1	0	0	10	137	7	182	14	270	30	4	12	2	7	7	1.4	0	0
10	4	9	1	0	0	8	126	6	179	13	300	30	4	10	1	6	6	1.7	0	0
11	1	3	1	10	27	41	85	42	92	61	215	96	30	52	20	48	48	1.2	10	27
11	1	4	3	155	557	43 4	79 12	40 5	99 8	62 4	174 9	96 0	30 7	52 2	22 4	53 1	55 4	1.2 .1	52 50	186 209
11	1	5	1	16	27	48	106	52	141	69	215	90	36	60	16	45	45	1.3	16	27
11	1	6	2	26	90	44 5	86 10	39 7	119 27	58 6	170 14	96 0	25 10	53 1	15 0	44 2	51 12	1.3 0	13 0	45 42
11	1	9	1	29	107	38	74	38	116	60	200	96	24	50	20	40	48	1.1	27	107
11	2	3	1	4	13	36	96	33	122	50	260	75	24	42	11	36	38	1.4	4	13
11	2	4	3	88	482	35 1	85 14	31 2	113 19	48 2	158 19	75 0	21 3	44 1	15 7	40 5	42 7	1.3 .3	29	141 158
11	2	5	1	10	32	32	98	27	131	50	300	70	19	40	11	32	33	1.3	10	32
11	2	6	2	21	131	32 4	104 16	30 0	141 28	50 2	245 7	75 0	19 1	43 1	7 4	33 4	31 1	1.6 .2	10 11	66 0
11	2	9	1	44	96	34	97	32	146	52	290	75	18	45	14	34	35	1.2	44	96
11	3	3	1	16	41	18	126	12	147	21	180	53	10	20	2	13	14	1.7	16	41
11	3	4	2	48	106	29 4	110 25	16 0	130 26	32 6	226 78	53 0	14 1	27 4	6 1	21 1	22 1	1.5 0	24 0	53 61
11	3	5	1	11	38	26	139	16	148	32	208	53	16	28	0	15	19	2.0	11	38
11	3	6	2	26	53	28 3	152 16	17 1	165 3	33 1	213 7	53 0	15 3	30 1	4 0	16 2	18 0	1.5 .1	13 8	26 2
11	3	9	1	63	98	16	110	9	141	22	245	53	6	19	2	14	14	1.7	63	98
11	4	4	1	0	0	11	146	6	173	16	250	30	4	13	1	6	8	1.7	0	0
11	4	6	1	0	0	16	192	8	208	18	260	30	8	16	0	4	8	2.0	0	0
11	4	9	1	0	0	6	141	3	201	9	300	30	2	18	0	4	4	2.0	0	0
12	1	3	1	35	36	43	100	24	117	59	195	90	19	50	14	43	43	1.3	35	36
12	1	4	18	975	1602	43 10	87 14	34 11	123 15	60 13	180 39	90 0	20 9	55 11	17 3	47 7	49 6	1.2 .2	54 127	89 153
12	1	5	4	87	167	31 11	76 14	21 11	110 14	44 17	165 48	90 0	12 7	40 13	16 3	36 11	40 9	1.1 .3	22 27	42 49
12	1	6	5	204	277	45 10	85 17	30 3	125 13	65 10	195 31	90 0	17 6	58 8	21 4	50 5	52 6	1.2 .2	41 37	55 48
12	1	9	1	48	48	49	102	17	107	66	215	90	16	51	16	48	48	1.3	48	48
12	2	3	1	11	17	29	112	20	143	37	188	70	14	35	8	26	26	1.4	11	17
12	2	4	16	831	1438	32 7	98 13	16 6	122 16	41 10	166 33	70 1	11 4	38 8	10 3	33 6	33 5	1.4 .2	52 90	90 152
12	2	5	5	305	469	24 7	90 12	11 4	118 24	32 10	194 69	70 0	7 2	29 9	8 1	25 7	26 6	1.3 .2	61 71	94 87
12	2	6	5	270	354	29 4	101 8	14 4	133 10	41 6	212 18	70 0	10 4	35 5	9 2	29 4	29 4	1.3 .1	54 55	71 68
12	2	9	2	98	138	34 6	96 10	12 0	118 1	44 8	186 6	70 0	14 8	39 4	8 .1	34 4	35 2	1.6 .1	49 48	69 52
12	3	3	1	13	50	18	100	6	128	21	150	50	4	20	5	18	18	1.4	13	50
12	3	4	6	240	377	17 3	106 6	7 5	124 12	21 4	158 31	50 0	6 5	20 4	3 1	16 4	16 3	1.7 .1	40 51	63 82
12	3	5	5	798	1221	14 2	109 12	5 1	133 24	19 3	232 79	50 0	3 1	15 2	3 2	12 2	12 1	1.6 .3	160 161	244 287
12	3	6	1	44	50	20	104	7	113	24	175	50	6	21	4	19	19	1.6	44	50

GROWTH TYPE	SITE INDEX CLASS	ZONE NO.	NO. CURVES IN CLASS	NO. PLOTS TO R_A	TOTAL NO. PLOTS	YIELDS IN C_{CF}/ACRE, ROTATIONS IN YEARS ± STANDARD DEVIATIONS — MATURE 7.1"D+ OR 9.1"D+ $\bar{X}Y_A$	$\bar{X}R_A$	MATURE 11.1"D+ OR 13.1"D+ $\bar{X}Y_B$	$\bar{X}R_B$	OVERMATURE 7.1"D+ OR 9.1"D+ $\bar{X}Y_C$	$\bar{X}R_C$	AVE. SITE INDEX ± SD	SUPPLEMENTARY YIELDS C_{CF}/ACRE — 11.1"D+ OR 13.1"D+ $\bar{X}Y_A'$	7.1"D+ OR 9.1"D+ $\bar{X}Y_B'$	7.1"D+ OR 9.1"D+ VP_{50}	VP_{100}	MAI cf/ACRE AT R_A	PAI % FOR 50 TO 100 YRS	AVE NO. PLOTS TO R_A ± SD	AVE NO. PLOTS TOTAL ± SD
12	3	9	1	77	100	12	100	15	135	16	155	50	2	16	2	12	12	1.9	77	100
12	4	4	1	0	0	8	121	2	135	10	185	30	2	8	1	6	7	1.7	0	0
12	4	5	1	0	0	6	130	6	147	7	220	30	1	6	0	4	5	2.0	0	0
12	4	6	1	0	0	10	138	3	170	12	270	30	2	11	1	6	7	1.7	0	0
12	4	9	1	0	0	6	130	2	157	7	182	30	2	6	1	4	5	1.5	0	0
13	1	3	2	27	54	46 3	89 7	33 4	101 8	54 2	224 36	90 0	22 3	58 2	21 1	52 1	52 1	1.2 0	14 1	27 4
13	1	4	16	438	1732	44 8	86 11	39 5	110 15	61 10	181 37	90 2	27 7	54 9	18 3	50 7	51 6	1.3 .2	27 46	108 173
13	1	5	3	63	149	35 6	77 15	30 7	105 19	50 9	163 36	90 0	18 3	45 10	19 8	43 8	47 13	1.1 .2	21 25	50 30
13	1	6	6	103	372	35 5	74 9	27 2	101 10	64 6	206 50	91 2	18 3	46 5	22 .3	44 3	47 4	1.0 .1	17 14	62 81
13	1	9	1	11	38	38	83	32	123	52	180	90	18	50	16	44	46	1.3	11	38
13	2	3	1	4	13	30	104	14	126	37	170	70	12	34	4	27	29	1.7	4	13
13	2	4	13	305	818	32	90	20	117	42	164	70	14	38	15	34	35	1.1	24	63
13	2	5	4	113	225	27 6	94 7	16 3	117 7	37 9	198 64	75 10	12 3	32 8	9 2	28 6	29 6	1.4 .1	28 23	56 39
13	2	6	6	141	301	27 4	95 19	18 6	138 34	39 5	205 35	70 0	25 32	35 5	8 3	26 6	29 3	1.5 .2	24 33	50 72
13	2	9	2	32	77	32 11	100 28	18 8	137 27	42 11	179 41	70 0	12 6	40 11	10 3	30 2	31 2	1.3 .2	16 0	38 25
13	3	3	1	5	8	22	113	10	129	28	190	50	8	25	3	20	20	1.7	5	8
13	3	4	4	112	182	22	109 5	11 12	129 4	26 13	123 10	50 0	8 3	25 6	5 1	19 4	20 3	1.6 .3	28 31	46 51
13	3	5	3	84	158	25 3	130 17	15 6	180 20	30 2	208 14	50 0	12 5	28 3	5 1	17 2	19 1	1.5 .2	28 28	53 42
13	3	6	4	96	129	16 4	101 14	11 5	119 6	20 4	199 31	50 0	9 5	18 3	4 2	16 2	16 2	1.6 .3	24 28	32 35
15	3	9	1	44	69	16	106	6	123	19	150	50	4	18	2	16	16	1.7	44	69
13	4	3	1	0	0	16	137	7	165	20	260	30	6	18	2	10	12	1.6	0	0
13	4	4	1	0	0	8	129	4	153	10	200	30	2	10	2	6	6	1.3	0	0
13	4	5	1	0	0	6	119	3	150	8	235	30	2	7	1	5	5	1.6	0	0
13	4	6	1	0	0	8	144	3	161	10	270	30	2	9	2	5	6	1.2	0	0
13	4	9	1	0	0	8	138	2	159	10	185	30	2	9	0	5	6	2.0	0	0
14	1	4	1	100	107	41	93	32	180	58	200	90	23	50	16	44	44	1.3	100	107
14	1	5	1	13	21	36	93	26	109	54	170	90	12	48	21	46	49	1.1	13	21
14	2	4	1	37	45	24	78	14	109	32	150	70	9	30	12	28	31	1.1	37	45
14	2	5	1	19	24	26	99	14	123	35	165	70	10	32	6	27	26	1.6	19	24
14	3	4	1	6	10	14	81	8	127	20	160	50	3	18	6	16	17	1.2	6	10
14	4	4	1	0	0	7	111	2	190	10	220	30	2	8	2	6	6	1.3	0	0
15	2	2	1	1	37	21	20	18	34	50	105	100	10	32	40	49		.4	1	37
15	2	4	1	62	104	24	66	18	83	34	128	90	14	29	17	32	36	.9	62	104
15	2	6	1	20	24	34	69	41	84	43	135	90	18	41	20	42	49	1.0	20	24
15	3	2	1	8	40	15	29	16	59	36	105	60	6	28	25	36	52	.6	8	40
15	3	4	1	40	48	11	65	5	84	13	103	65	3	12	8	13	17	.8	40	48
15	3	6	1	2	3	6	55	4	88	7	88	65	2	7	5	7	11	.6	2	3
15	3	9	1	20	29	16	83	7	105	20	137	65	5	18	7	18	19	1.2	20	29
15	4	2	1	0	0	8	72	5	93	16	120	30	3	15	8	16	11	1.0	0	0
15	4	4	1	0	0	4	90	2	125	6	180	30	1	5	2	4	4	1.0	0	0
15	4	6	1	0	0	2	84	1	100	2	105	30	1	2	1	2	2	1.0	0	0
15	4	9	1	0	0	6	98	2	120	7	130	30	2	7	2	6	6	1.3	0	0
16	2	2	1	7	69	15	19	18	41	42	130	100	6	28	32	42	79	.5	7	69
16	2	4	1	90	97	21	73	13	82	26	120	90	12	23	12	25	29	1.0	90	97
16	2	6	1	21	25	21	65	12	72	26	105	90	11	22	15	26	32	.8	21	25
16	2	9	2	84	121	24 3	94 13	11 1	122 4	34 8	166 5	90 0	10 1	26 2	8 1	25 1	26 1	1.3 .1	42 27	60 44
16	3	2	1	17	50	16	26	22	58	42	143	60	8	32	28	40	62	.6	17	50
16	3	4	1	15	63	8	62	4	73	10	115	65	4	9	6	10	13	.8	15	63
16	3	6	1	14	17	21	69	8	76	26	110	65	8	24	14	26	30	.9	14	17
16	3	9	1	29	30	18	110	6	134	20	150	65	4	20	2	16	16	1.7	29	30
16	4	2	1	0	0	10	63	8	124	16	180	30	3	15	7	14	16	1.0	0	0
16	4	4	1	0	0	3	82	1	180	4	160	30	1	4	2	4	4	1.0	0	0
16	4	6	1	0	0	8	91	2	120	10	180	30	2	10	3	8	9	1.2	0	0
16	4	9	1	0	0	6	118	2	152	6	160	30	2	6	0	4	5	20	0	0

APPENDIX II

BRITISH COLUMBIA FOREST SERVICE VOLUME/AGE CURVES:
ORIGINAL DATA NOT USED IN SUMMARIES FOR APPENDIX I.

British Columbia Forest Service Volume/Age Curves:
Original Data Not Used in Summaries For Appendix I.

VAC No.	Growth Type	Species Group	Zone	Site	Close Utilization: Yield Ccf A	RA Years	Yield Ccf B	RB Years	Yield Ccf C	RC Years	No. Plots: To RA	Total	Site Index	Yield Ccf A'	Yield Ccf B'	VP50 Ccf	VP100 Ccf	U Limit
642	10		0	4	34	175	28	195	40	233	0	0	40	24	38	0	14	1
880	10		0	3	60	146	57	165	76	235	2	19	53	50	66	2	36	1
880	10		0	3	58	130	58	155	77	230	2	19	53	47	68	10	42	2
879	10		0	2	82	92	83	106	132	320	8	100	75	70	92	31	88	1
879	10		0	2	82	88	86	102	134	320	4	100	75	72	94	36	92	2
878	10		0	1	102	78	109	92	174	320	5	61	96	90	125	58	125	1
878	10		0	1	125	77	100	80	173	310	5	61	96	96	106	60	127	2
178	15		7	1	36	35	44	50	107	220	13	55	140	29	50	50	80	1
179	15		7	1	43	45	47	58	106	230	13	54	140	35	54	48	78	2
180	15		7	2	48	91	54	98	72	195	53	77	100	48	60	7	60	1
219	8		6	3	20	115			28	290	3	20	53			3	18	3
218	8		6	2	26	96			37	230	3	60	75			9	28	3
217	8		6	1	80	38			56	225	3	42	96			18	46	3
216	7		6	3	46	176			52	225	12	56	60			0	15	3
215	7		6	2	59	147			83	300	29	103	90			4	33	3
214	2		6	3	22	142			26	230	12	20	65			0	12	3
213	2		6	2	44	137			62	218	47	55	80			8	30	3
212	2		6	1	44	95			74	250	45	79	100			17	46	3
183	15		7	3	16	67	13	80	20	150	17	28	60	10	18	10	20	2
182	15		7	3	17	58	15	79	24	130	17	28	60	10	21	17	24	1
181	15		7	2	56	94	53	104	72	195	53	77	100	48	60	14	58	2
804	13		4	3	15	116	6	129	18	160	79	108	50	4	16	2	12	1
803	13		4	2	28	106	12	127	36	190	177	363	70	9	32	6	28	1
802	13		4	1	42	94	28	122	59	210	410	737	90	20	52	13	44	1
801	12	28	4	3	9	116	2	134	12	200	147	193	50	2	10	0	8	1
800	12	28	4	2	24	117	6	137	34	270	503	635	70	5	28	4	20	1
799	12	28	4	1	47	117	24	148	62	250	610	680	90	16	56	10	39	1
873	6		1	3	35	85	38	135	59	320	2	41	70	19	49	18	40	2
872	6		1	2	56	69	58	92	102	310	2	84	110	44	72	35	72	2
877	8		1	3	46	112	54	134	90	320	0	39	70	44	62	16	46	2
876	8		1	2	72	80	76	102	122	320	0	92	110	56	87	39	88	2
875	7		1	3	48	78	52	114	84	320	2	202	70	32	64	28	59	2
874	7		1	2	58	68	64	94	118	320	6	264	110	44	76	41	80	2
870	5		1	2	75	78	79	91	122	320	1	42	110	66	86	42	92	2
871	5		1	3	34	78	38	108	78	300	2	212	70	25	44	19	42	2

APPENDIX III

NUMBERS OF TREES/ACRE FOR CERTAIN DIAMETER LIMITS FROM $\bar{V}$/TREE

TABLE I: NUMBERS OF TREES/ACRE FOR CERTAIN DIAMETER LIMITS FROM $\overline{V}$/TREE (AFTER SMITH, 1967a) FOR DOUGLAS FIR TYPES.

Species Predom	Site Index	Stand Density	RA Years	DA In.	NO. TREES/AC. 3.1"+	7.1"+	11.1"+	RB Years	DB In.	NO. TREES/AC. 3.1"+	7.1"+	11.1"+
D.Fir	80	O	98	25.9	72	62	42	125	33.0	43	76	32
		N		15.7	242	208	141		20.0	86	78	63
		D		8.0	857	738	500		12.5	328	296	240
	100	O	82	27.1	71	63	46	105	34.6	55	49	39
		N		16.4	282	250	186		21.0	110	98	78
		D		10.2	1000	886	659		13.1	275	245	195
	120	O	87	34.4	79	71	57	104	41.2	68	63	55
		N		20.9	158	142	116		25.0	133	124	107
		D		13.0	595	534	435		15.6	499	419	364
	160	O	65	34.3	106	93	80	81	42.8	76	69	62
		N		20.8	212	188	161		26.0	151	137	124
		D		13.0	800	708	608		16.2	504	459	415
	AV.	O	90	27.0	73	65	48	115	34.3	50	44	33
		N		16.4	239	211	156		20.8	99	87	65
		D		9.2	860	760	560		13.0	311	273	205

TABLE II: NUMBERS OF TREES/AC. FOR CERTAIN DIAMETER LIMITS FROM $\bar{V}$/TREE (AFTER SMITH, 1967a) FOR SPRUCE TYPES.

Species Predom.	Site Index	Stand Density	RA Years	$\bar{D}A$ In.	NO. TREES/AC.			RB Years	$\bar{D}B$ In.	NO. TREES/AC.		
					3.1"+	7.1"+	11.1"+			3.1"+	7.1"+	11.1"+
Spruce	60	O	120	19.8	113	92	55	144	28.5	56	49	31
		N		12.0	569	465	276		17.3	102	89	57
		D		7.8	1000	818	485		10.8	452	393	250
	80	O	93	24.6	99	84	55	121	31.9	55	47	34
		N		14.9	283	241	159		19.4	110	93	68
		D		9.3	837	714	469		12.1	419	355	258
	100	O	82	27.1	80	72	53	103	34.0	60	55	45
		N		16.4	319	288	212		20.6	120	110	90
		D		10.2	1133	1022	756		12.9	298	274	224
	AV.	O	98	23.9	93	79	55	122	31.5	57	50	38
		N		14.5	339	290	202		19.1	111	98	73
		D		9.1	1000	857	595		12.0	362	319	239

TABLE III: NUMBERS OF TREES/ACRE FOR CERTAIN DIAMETER LIMITS FROM $\overline{V}$/TREE (AFTER SMITH, 1967a) FOR LODGEPOLE PINE TYPES.

Species Predom	Site Index	Stand Density	RA Yrs.	$\overline{D}$A In.	NO. TREES/AC. 3.1"+	7.1"+	11.1"+	RB Years	$\overline{D}$B In.	NO. TREES/AC. 3.1"+	7.1"+	11.1"+
Lodge-pole Pine	60	O	96	19.0	137	105	46	124	24.6	77	64	29
		N		11.5	600	462	200		14.9	257	216	96
		D		7.2	1258	968	419		9.3	754	632	281
	80	O	86	22.7	106	93	45		30.6	62	50	31
		N		13.8	379	331	161	116	18.6	124	100	61
		D		8.6	887	774	377		11.6	471	377	232
	100	O	82	27.1	68	53	27	112	37.0	32	30	19
		N		16.4	272	212	109		22.4	84	79	51
		D		10.2	962	750	385		14.5	210	198	127
	AV.	O	91	21.0	111	93	44	120	30.3	66	53	29
		N		12.8	443	371	175		18.4	152	124	68
		D		8.0	977	818	386		11.5	535	436	238

TABLE IV: NUMBERS OF TREES/ACRE FOR CERTAIN DIAMETER LIMITS FROM $\overline{V}$/TREE (COMBINED-VARIABLE TECHNIQUE, SMITH AND BREADON, 1964) FOR DOUGLAS FIR TYPES.

Species Predom	Site Index	Stand Density	RA y.Yrs.	$\overline{D}$A In.	NO. TREES/AC.			RB Years	$\overline{D}$B In.	NO. TREES/AC.		
					3.1"+	7.1"+	11.1"+			3.1"+	7.1"+	11.1"+
D.Fir	80	O	98	25.9	46	40	27	125	33.0	27	24	20
		N		15.7	116	100	68		20.0	67	60	49
		D		8.0	396	341	231		12.5	145	131	106
	100	O	82	27.1	50	44	33	105	34.6	31	28	22
		N		16.4	127	112	84	105	21.0	79	70	56
		D		10.2	286	253	188		13.1	168	150	119
	120	O	87	34.4	48	43	35	104	41.2	32	30	26
		N		20.9	115	103	84		25.0	79	74	64
		D		13.0	274	246	200		15.6	161	150	130
	160	O	65	34.3	64	57	49		42.8	40	36	33
		N		20.8	155	137	118		26.0	99	90	82
		D		13.0	365	323	277		16.2	201	183	165
	AV.	O	90	27.0	49	43	32	115	34.3	24	22	18
		N		16.4	124	110	81		20.8	75	68	56
		D		9.2	344	304	224		13.0	82	144	119

TABLE V: NUMBERS OF TREES/ACRE FOR CERTAIN DIAMETER LIMITS FROM $\bar{V}$/TREE (COMBINED-VARIABLE TECHNIQUE, SMITH AND BREADON, 1964) FOR SPRUCE TYPES.

Species Predom.	Site Index	Stand Density	RA Years	$\bar{D}A$ In.	NO. TREES/AC. 3.1"+	7.1"+	11.1"+	RB Years	$\bar{D}B$ In.	NO. TREES/AC. 3.1"+	7.1"+	11.1"+
Spruce	60	O	120	19.8	73	60	36	144	28.5	32	28	18
		N		12.0	194	159	94		17.3	78	68	43
		D		7.8	458	375	222		10.8	191	166	106
	80	O	93	24.6	52	44	29	121	31.9	32	27	20
		N		14.9	121	104	68		19.4	80	67	49
		D		9.3	323	276	181		12.1	172	146	106
	100	O	82	27.1	49	45	33	103	34.0	30	28	23
		N		16.4	120	108	80		20.6	78	71	58
		D		10.2	304	274	202		12.9	172	158	129
	AV	O	98	23.9	57	49	34	122	31.5	32	28	21
		N		14.5	132	114	79		19.1	79	70	52
		D		9.1	353	302	210		12.0	169	149	112

TABLE VI: NUMBERS OF TREES/ACRE FOR CERTAIN DIAMETER LIMITS FROM $\overline{V}$/TREE (COMBINED-VARIABLE TECHNIQUE, SMITH AND BREADON, 1964) FOR LODGEPOLE PINE TYPES.

Species Predom.	Site Index	Stand Density	RA Years	$\overline{D}$A In.	NO. TREES/AC. 3.1"+	7.1"+	11.1"+	RB Years	$\overline{D}$B In.	NO. TREES/AC. 3.1"+	7.1"+	11.1"+
Lodge-Pole Pine	60	O	96	19.0	89	69	30	124	24.6	47	39	17
		N		11.5	229	176	76		14.9	122	102	45
		D		7.2	574	441	191		9.3	299	250	111
	80	O	86	22.7	64	56	27	116	30.6	37	30	18
		N		13.8	165	144	70		18.6	98	78	48
		D		8.6	412	360	175		11.6	239	191	118
	100	O	82	27.1	41	32	16	112	37.0	17	16	10
		N		16.4	108	184	43		22.4	46	44	28
		D		10.2	263	205	105		14.0	115	108	69
	AV	O	91	21.0	74	62	29	120	30.3	28	23	12
		N		12.8	187	156	74		18.4	74	60	33
		D		8.0	467	391	185		11.5	181	148	80

APPENDIX IV

FORTRAN SOURCE LIST

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  ISN       SOURCE STATEMENT

     0 * $IBFTC TONY                                                                  *
     1 *        DIMENSION N(22),X(22),SUM(22),SSQ(22),AVE(22),STD(22),NAME(22)        *
     2 *        DIMENSION TITL(13),XN(22)                                             *
     3 *        READ (5,25) (NAME(I),I=1,15)                                          *
    10 * 25     FORMAT (13A6/2A6)                                                     *
    11 * 13     DO 100 I=1,15                                                         *
    12 *        XN(I) = 0.                                                            *
    13 *        SUM(I)  = 0.                                                          *
    14 *        STD(I) = 0.                                                           *
    15 *         SSQ(I) = 0.                                                          *
    16 * 100    CONTINUE                                                              *
    20 *        READ (5,15) (TITL(I),I=1,13)                                          *
    25 * 15     FORMAT(13A6)                                                          *
    26 *        WRITE (6,15) (TITL(I),I=1,13)                                         *
    33 *        WRITE (6,8)                                                           *
    34 * 12       READ(5,2) NGT,NZONE,NSITE,(X(I),I=1,13),NULMT,NED                   *
    46 * 2      FORMAT (3X,I2,2X,2I1,F4.1,F3.0,F4.1,F3.0,F4.1,F3.0,F3.0,F4.0,F3.0,    *
       *       14F4.1,I1,6X,I1)                                                       *
    47 *        X(14) = X(1) / X(2) * 100.                                            *
    50 *        X(15) = ((X(13)-X(12))/(50.*X(13))*100.)                              *
    51 *        IF(NSITE.EQ.0) STOP                                                   *
    54 *        DO 16 I=1,15                                                          *
    55 *        IF (X(I).EQ.0.) GO TO 16                                              *
    60 *        XN(I) = XN(I) + 1.                                                    *
    61 * 16       CONTINUE                                                            *
    63 *        DO 10 I=1,15                                                          *
    64 *        SUM(I) = SUM(I) + X(I)                                                *
    65 *        SSQ(I) = SSQ(I) + X(I) * X(I)                                         *
    66 * 10     CONTINUE                                                              *
    70 *        IF(NED.NE.1) GO TO 12                                                 *
    73 *        DO 111 I=1,15                                                         *
    74 *        AVE(I) = SUM(I) / XN(I)                                               *
    75 *        IF(XN(I).EQ.1.) GO TO 111                                             *
   100 *        STD(I) = SQRT((SSQ(I)-SUM(I)*SUM(I)/XN(I))/(XN(I)-1.))                *
   101 * 111    CONTINUE                                                              *
   103 *        WRITE (6,3) (NAME(I),I=1,15)                                          *
   110 * 3      FORMAT (10X,15(2X,A6))                                                *
   111 *        WRITE (6,7) (XN(I),I=1,15)                                            *
   116 * 7      FORMAT (1X,8H NO.OBS.,1X,15F8.0)                                      *
   117 *        WRITE (6,4) (SUM(I),I=1,15)                                           *
   124 * 4      FORMAT (/1X,4H SUM , 5X,15F8.1)                                       *
   125 *        WRITE (6,5) (AVE(I),I=1,15)                                           *
   132 * 5      FORMAT (1X,6H MEANS ,  3X,15F8.1)                                     *
   133 *        WRITE (6,6) (STD(I),I=1,15)                                           *
   140 * 6      FORMAT (1X,8H STD DEV , 1X,15F8.1)                                    *
   141 * 9      WRITE (6,8)                                                           *
   142 *        WRITE (6,8)                                                           *
   143 * 8      FORMAT (//)                                                           *
   144 *        GO TO 13                                                              *
   145 *        END                                                                   *
```