# A COMPARISON OF METHODS OF DETERMINING THE ALLOWABLE CUT ON THE UNIVERSITY OF BRITISH COLUMBIA RESEARCH FOREST, HANEY, B. C.

by

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## ABSTRACT

A COMPARISON OF METHODS OF DETERMINING THE ALLOWABLE CUT ON THE UNIVERSITY OF BRITISH COLUMBIA RESEARCH FOREST, HANEY, B. C.

Generally it is not adequate to calculate an allowable cut for a property by only one formula or method. Usually it is preferable to utilize all the information available with as many suitable formulae or methods as possible to obtain reasonable estimates of the yearly utilization rates by several approaches.

For the University Research Forest fifteen different formulae and methods were selected for comparison, because their basic assumptions appeared applicable to this forest. The methods and formulae tested were:

Methods: Area regulation, Area-volume check, Area-volume allotment, Barnes' and H. A. Meyer's.

Formulae: Austrian, Black Hills, Grosenbaugh, Hanzlik, Hundeshagen, Kemp, W. H. Meyer, S. Petrini (compound and simple interest) and Von Mantel.

Appropriate inventory techniques were developed in order to collect the necessary information regarding rates of growth, mortality and numbers of trees per acre by diameter classes. Present and future decadal growing stocks were estimated. Simple and compound growth rates, including and excluding

ingrowth, for all types were calculated separately for stands over eighty years of age and for stands under eighty years. The inventory was based on the areas and estimates taken from 1961 aerial photographs supplemented by both temporary and permanent sample plots, employing primarily the principles of the point sampling techniques as described by L. R. Grosenbaugh.

After substituting the actual data into the formulae and various methods, allowable cut estimates for 3.1, 9.1, 11.1, and 13.1 inches minimum diameter limits were calculated. Allowances were made for an intermediate standard of utilization and for waste, breakage and decay.

Considering the inventory and the allowable cut calculations it was found that:

1. Simple area regulation will lead to undesirably large fluctuations in allowable cut.

2. Volume formulae are useful means of determining the yearly harvest volume, though the distribution of the cut on the ground requires definition in terms of area as well.

3. Neither area nor volume control can be used exclusively. Some combination and integration is usually necessary in actual practice. In the case of the Research Forest this can be applied most conveniently by following the area-volume computation basis.

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# INTRODUCTION

The purpose of forest management, in general, is to supply the economy of a country with a continuous flow of forest products and to furnish the needs of the public for recreation, controlled water supply, fish and game, and protection.

The task of forest regulation within the scope of forest management is, in general, to supply well-designed plans, in order that the demands on the forests for timber production and other public benefits - such as soil preservation, flood protection, and recreation - can be met.

To satisfy these demands, the forests must be regulated in order to maintain the balance between forest utilization and forest growth, thus perpetuating cuttings and revenues connected with them. Its purpose, therefore, is not only to regulate the cuttings themselves but also to describe the reforestation and protection measures necessary to sustain continuous production.

Forest regulation must be joined by different economic operations in such a way that they merge the entire management unit into a harmonized working organization.

Usually natural forests are not in a stage where they can assure the most favourable sustained cut right from the beginning. The object of regulation is to direct the management unit in such a way that it will reach the desired balanced position with the least economic loss, in the shortest time.

This idea of preserving the forest and maintaining a sustained annual cut is not new. The earliest records of forest regulation date back as far as 1122 B.C. in China, where a Government Commission of Forests regulated the cutting of timber and punished thieves and trespassers (Meyer, Recknagel and Stevenson, 1952). In Europe during the feudal days, some forests were devastated due to overgrazing, and regulations became necessary to protect them. By the last half of the eighteenth century scientific methods were replacing the earlier methods, giving the basis for modern allowable cut calculations. Naturally, many of the earlier methods are still in practice, together with the new approaches, and are often used because of their simplicity or assumed applicability to a particular area. However, applying only one favored formula usually is not enough to justify an important decision on which the future of a large management unit depends. Usually it is better to apply several formulae and methods for the determination of the allowable cut, and compare the results.

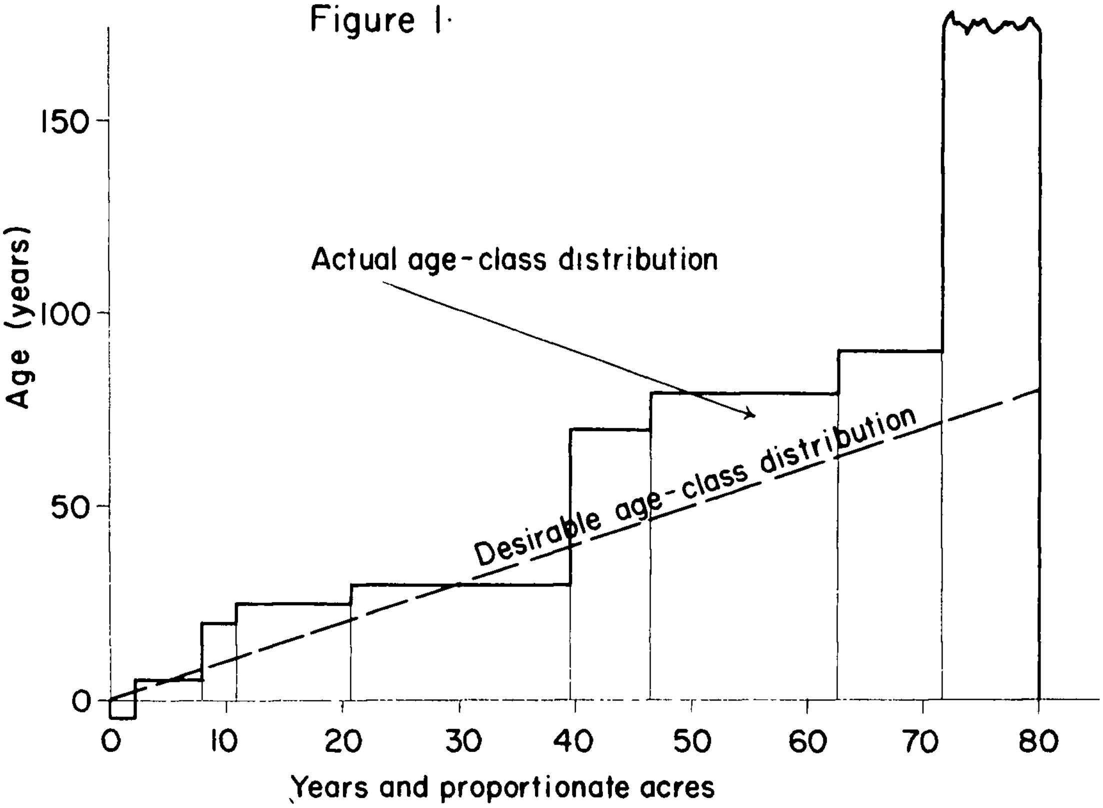
The comparison of various formulae and methods, to aid decision as to which regulation method is most suited to a particular area, was emphasized by Greeley (1935), who evaluated changes in plan techniques and concepts for the Snoqualmie National Forest of the United States. Similarly, Castles (1959) suggested "that to rely on any one method or formula for setting the allowable harvest cut for a management type or working cycle is not as sound as it is to make the calculation by as many formulae as there are sound data with which to calculate."

Naturally, allowable cut volumes, whenever possible, should be allocated to specific stands. There must also be provision for, and recognition of, the need for periodic revision. Flexibility within reasonable limits should be the aim. In general: "Regulatory methods should be regarded as the key working tools of the practising forester, to be used with discretion and understanding" (Davis, 1954).

Since the University Research Forest near Haney was used as the basis for all comparisons in the thesis, a general visual impression of the present distribution of age classes and volume on the Forest should be gained from study of Figures 1 and 2. The University Research Forest is almost unique among Coastal British Columbia forests in its relatively balanced distribution of age classes and its lack of an overwhelming surplus of overmature timber.

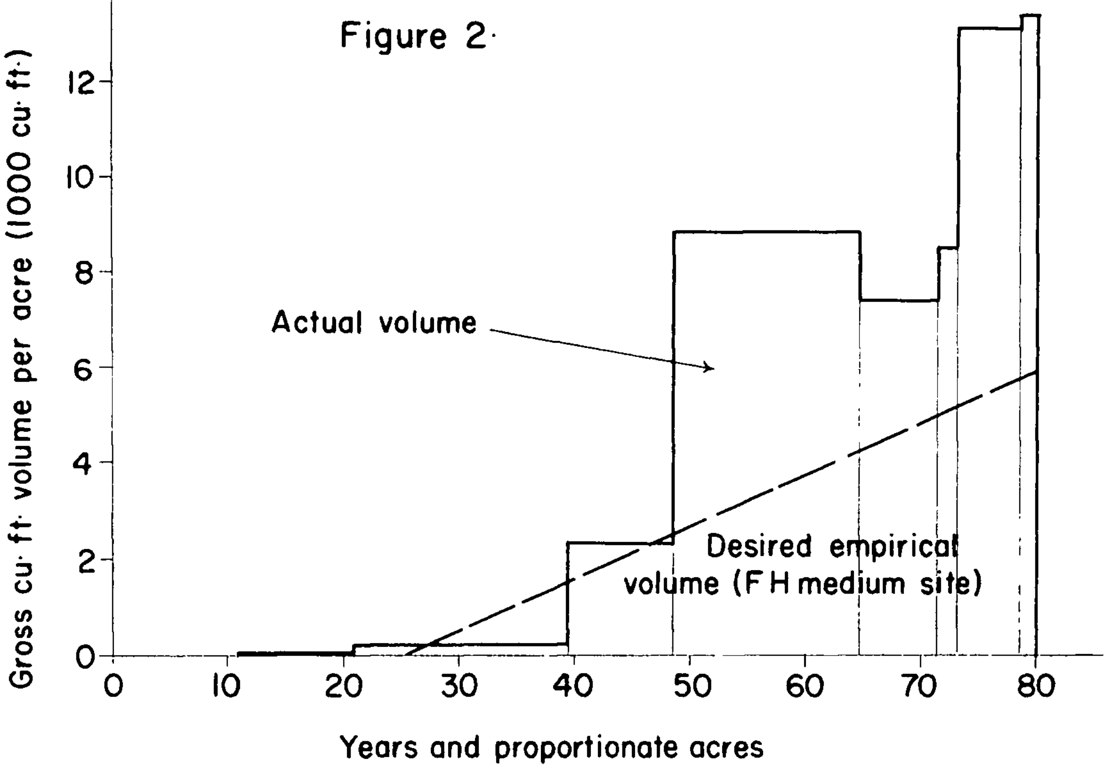
Actual and desired age-class distribution in the U·B·C· Research Forest·

Figure 1·




Actual and desired gross cu· ft· volumes in the U·B·C· Research Forest· (11·1 in· +)

Figure 2·



## METHODS OF CALCULATING THE ALLOWABLE CUT

Throughout the history of forestry, many methods have been developed for calculating the allowable cut in various countries for many different forest stands. The principal steps toward forest regulation were taken in Europe, where the necessity of planned forest management arose soon after the effect of excessive utilization was realized. Although many allowable cut methods have been developed, they can be grouped into three basic procedures. These principal methods are usually named as:

1. Area control
2. Volume control
3. Area-volume control, or combined methods.

### 1. Area control

The principle of area control is very simple: it means that the volume to be harvested is controlled by the area allocated for cutting. The forest under management is divided into a number of areas, each of which is cut according to a definite cutting schedule.

The simplest expression of area control is in a fully regulated even-aged forest, managed according to a clear cutting plan. Then each year of period 1/R or 1/P of the area is clear cut (R = rotation in years; P = period in years), assuming that the area is of the same site quality. Where different qualities of land are present, it is necessary firest to reduce the areas to equal productivity, then to determine the yearly or periodic cutting area, in order to obtain a fairly even flow of products during the rotation. In practice, of course, no forest could be so perfectly regulated that a uniform area could be cut over each year and precisely the same volume obtained. Considerable variations in the yearly cutting areas usually must be introduced. However, this flexibility does not, and should not, lessen the importance of the basic framework.

2. Volume control

In volume control, the determination of the cut is approached through the volume of the growing stock and its increment, and can be approximated with various mathematical formulae. In contrast to the area method, where areas of the same productivity are cut during each year of the rotation, the volume method intends to secure an equal volume for each year or period. Usually with some general information about the forest the volume control method gives a sufficiently good guide to the forester to prevent serious mistakes, when urgent estimation of allowable cut is necessary (Davis, 1954).

These methods are based either on growing stock or on increment, or, on both growing stock and increment, and they can be applied to even-aged forests as well as to uneven-aged forests. However, the volume control is "most readily and realistically applied to uneven-aged stands where volume and increment estimates are necessary for management planning at all" (Davis, 1954).

3. Area and volume control

Since neither area nor volume control provides a complete solution to the problem of determining the allowable cut in a forest other than one completely regulated, it is logical to utilize the advantages of both methods and combine them in one way or another. Thus many methods have been devised and there are endless possibilities to create new ones to meet particular circumstances. In general, these methods are characterized by flexibility and lack the precision and neatness of volume methods. They are difficult to describe in a few words, since they are more of a procedure or a framework, rather than a specific method. Methods of calculation will be presented later, when the actual calculation for the University Research Forest will be shown.

# DESCRIPTION OF METHODS USED

Several methods were selected from each basic procedure previously mentioned. The selection was made according to their suitability to the natural even-aged stands of the Research Forest, which may have a range of up to 20 years in ages of dominant and codominant trees. Many methods are applicable to both even- and uneven-aged stands and give reasonable estimates for both cases.

## Area Control Methods

### Area regulation

For this method, described by H. H. Chapman (1950), it is important to obtain areas and site conditions for each forest type. If the ages of these stands are also available, then the yearly cutting volumes can be shown. The actual areas must be reduced to standard productivity, using the average or the most commonly occurring condition class as a base. After the area reduction, the yearly cutting area may be calculated as the total reduced area divided by the rotation age.

The order of cutting should follow the logical sequence of stands most needing removal; deteriorating mature stands, or stands least in value, must be cut first. Younger stands may be selected for cutting if other important reasons suggest the necessity of cutting, e.g. epidemics, or exceptionally good markets for smaller logs.

## Volume Control Methods

### Hanzlik's formula

The method recommended by E. J. Hanzlik (1922), and in a revised form by the West Coast Forest Procedures Committee (1950), is widely used in the western coast forests of North America. Hanzlik's method gives a reasonable volume estimate of the allowable cut for areas with large virgin timber reserves.

For use at the Research Forest, the formula has been defined as:

$$\text{A. C.} = I_{80} + \frac{Vmat}{R} ;$$

where A. C. is allowable yearly cut,

$I_{80}$ is mean annual increment at 80 years for stands younger than rotation age,

R is rotation age (years), and

Vmat is volume of mature stands (above rotation age).

The $I_{80}$ value is obtained from empirical yield tables (Fligg, 1960) for immature stands. Empirical mean annual increments of those second growth stands which are close to the cutting age are corrected by their present volume ratio

$$\text{Volume Ratio (VR)} = \frac{\text{present actual volume}}{\text{present empirical volume}} .$$

### Austrian formula

This formula differs from Hanzlik's in that the actual volume of the growing stock is adjusted to the level of the desired growing stock over the period of the rotation, whereas in Hanzlik's formula the entire volume of old growth timber is removed during the rotation. The increment used in the Austrian formula is the mean annual increment of the entire stand at present.

The formula is:

$$A.\ C. = I + \frac{Ga - Gr}{R}$$

as presented by K. P. Davis (1954),

where A. C. is allowable cut,

I is mean annual increment during the conversion period,

Ga is actual growing stock,

Gr is desired growing stock, and

R is rotation age in years.

In Heyer's formula, which is a modification of the Austrian, the volume of the growing stock is adjusted over a period which is generally much shorter than the rotation.

Kemp's formula

If volumes and areas by stand size classes are available, this formula is easy to apply. It is used in properties on which there is a surplus of timber beyond rotation age. The objective in application is to determine the cut that will achieve an approximately equal distribution of area by age or tree size classes within a rotation with a minimum variation from ultimate sustained yield volumes.

For a forest type the expression is:

$$A.\ C. = \frac{7A + 5A_1 + 3A_2 + A_3}{4R} \quad (MA)$$

(U.S. Dept. of Agric., 1958),

where A. C. is annual cut,

- $A$ is area of sawtimber stands,
- $A_1$ is area of poletimber stands,
- $A_2$ is area of seedling and sampling stands,
- $A_3$ is non-stocked area,
- $R$ is rotation in years, and
- $MA$ is expected average volume per acre of stands as they are cut.

The formula simply represents the distribution of volumes as they should be in a normal forest, i.e., in a triangular diagram of the growing stock in a normal forest, the forest should have:

1/16 of its volume in stands between 0 and 1/4 rotation age,
3/16 of its volume in stands between 1/4 and 1/2 " ",
5/16 of its volume in stands between 1/2 and 3/4 " ",
7/16 of its volume in stands between 3/4 and rotation age.

This model itself is erroneous in that volume plots"over age as a second or third degree curve instead of a straight line. This error is comparatively minor, however, and applies to some other allowable cut formulae as well" (U.S. Dept. of Agric., 1958).

Barnes' method (Barnes, 1951)

Since the annual cut is closely related to the age at which the stands are harvested, an estimate of the average cutting age during the forest rotation should furnish a good estimate of the annual cut. Therefore, in Barnes' method the average present age must be calculated, to see whether it is over or under the average age of a normal forest, with an average cutting age equal to the rotation. For example, in a normal forest with an average cutting age of 80 years, the present average age should be 40 years, but if the average age of the forest is more, or less, than 40 years, a discrepancy will occur, with which the average cutting age must be corrected. The yield at this corrected average cutting age will give a reasonable estimate of the yearly cut according to the hypothesis.

Since empirical yield tables are available for British Columbia, the average yield can be read directly from the yield tables for different types. The weighted average of these yields at the calculated rotation age then will give the allowable cut, based on Barnes' assumption.

Black Hills formula

This formula has been applied on the National Forests in the Black Hills of South Dakota, as described by K. P. Davis

(1954). Two broad condition classes of merchantable timber are recognized:

1. Mature stands, in which it is presumed current losses equal increment.
2. Thrifty merchantable stands, making net increment.

The formula is as follows:

$$A.\ C. = \frac{VM\ (CM) + \left[Vt + (It/2)\right]\ Ct}{Y}\ ;$$

where A. C. is allowable cut,

| | |
|---|---|
| VM | is volume of mature stands, |
| CM | is per cent cut in mature stands, an arbitrary figure, developed on the basis of silvicultural and related considerations, |
| Vt | is volume of thrifty merchantable stands, |
| It | is increment of thrifty merchantable stands during the cutting cycle, |
| Ct | is per cent cut in thrifty merchantable stands (an arbitrary figure determined in the same way as for CM), and |
| Y | is cutting cycle in years. |

Hundeshagen's formula

Hundeshagen's assumption was that growth or yield in an actual forest, approximately regular in distribution, bears the same relation to its total growing stock as growth in a fully stocked regulated forest, as represented by normal yield tables, bears to its growing stock (K. P. Davis, 1954). Expressed as a proportion:

$$\frac{Ya}{Ga} = \frac{Yr}{Gr} ;$$

where Ya is growth or yield in an actual forest,

Ga is growing stock in an actual forest,

Yr is growth or yield in a fully stocked forest, and

Gr is growing stock in a fully stocked forest.

The final equation is:

$$Ya = \frac{Yr}{Gr} Ga .$$

If the $\frac{Yr}{Gr}$ ratio is expressed as a percentage a quick approximation of the yield in the actual forest can be made by merely multiplying this percentage by the actual growing stock. This method, however, has many limitations regarding comparability of data, such as standards of utilization, effect of understocking and the like, inherent to the direct application of normal yield table data to actual stands. Although some of these factors can be eliminated using empirical yield tables, the method still should be used with caution and at best is useful only for a rough approximation.

Von Mantel's formula

It has been observed that in an approximately fully regulated forest there is a fairly regular and often linear increase in volume by age classes. This suggests the possibility that the growing stock can be represented by a right angled triangle. The area of this triangle therefore represents the total growing stock of the forest, "Ga", having the base of

"R" acres, and the altitude, the yield at rotation age, "Ya", indicating the annual cut. Thus the area of the triangle is given by the formula:

$$Ga = \frac{R(Ya)}{2} \quad ;$$

hence the actual yield is:

$$Ya = \frac{2Ga}{R} \; .$$

The accuracy of the formula is greatly affected by the regularity of the forest. It is obviously inapplicable unless there is some semblance of regularity.

Sven Petrini's (1956) compound and simple interest formulae

If the annual cut $\underline{m}$ is to be calculated for a period of $\underline{t}$ years, where the present wood capital is $\underline{k}$ cu. ft., the actual percentage of increment is $\underline{p}$ per cent and the final capital of wood is set as $\underline{K}$ cu. ft. at the end of $\underline{t}$ period; then $\underline{m}$ can be calculated using the compound interest formula:

$$m = 0.0p \; \frac{k(1.0p)^t - K}{1.0p^t - 1} \; .$$

If we assume that the capital $\underline{k}$ increases an equal annual amount, then the actual annual percentage increment in reality is continually diminishing during the period, which is usual for older stands. Thus the formula given below is better suited to stands with slow growth, while the equation above will more likely give a better answer for faster growing thrifty stands.

The simple interest formula is:

$$m = \frac{k(1 + \frac{tp}{100}) - K}{t(1 + \frac{tp}{200 + tp})} \quad .$$

In this formula it is assumed that the volume of the fellings, when made continually each year, can be reckoned as having been growing during half the period in question, i.e., t/2 years.

W. H. Meyer's amortization formula

This method, originally developed by W. H. Meyer in 1943, has been modified and described by him in 1952. It is almost identical to Sven Petrini's compound interest formula, except that Meyer includes ingrowth in his calculations, and therefore obtains a higher allowable cut volume than Petrini.

Meyer's formula is as follows:

$$A.\ C. = gM \frac{V_o(1 + gt)^m - V_m}{(1 + g_M)^m - 1} \quad ;$$

where A. C. is yearly allowable cut,

$g_M$ is compound growth rate for the merchantable stands alone excluding ingrowth,

$V_o$ is present volume,

$V_m$ is volume at the end of the period,

m is period for which the allowable cut is desired, and

gt is compound growth rate of the entire stand.

In comparing overall accuracy, the W. H. Meyer method can be judged more accurate, because of his corrections regarding ingrowth, than Petrini's formula.

Grosenbaugh's simple interest formula

Grosenbaugh (1956) developed his formula to suit the techniques of diagnostic tallies of basal area and assumes periodic remeasurements of the area for which the allowable cut estimation is desired. His formula has the advantages of separating speculative growth from measured growth rates, and of confining the allowable cut to a short period, for which periodic remeasurements of management plots are necessary.

The formula is:

$$\text{A. C.} = \left[\frac{1 + nG_2 - \frac{V_n}{V_o}}{nG_2}\right]\left[mG_1\right]\left[\frac{1 + \frac{m}{2}\ G_o}{1 + m\ G_o}\right]$$

where $n$ is number of years allowed between start of current period and time when ultimately desired stand will be attained,

$m$ is number of years in shorter period for which periodic allowable cut will be calculated,

$V_o$ is original stand volume at start of $\underline{m}$ year period,

$V_n$ is stand residual volume ultimately desired $\underline{n}$ years hence,

$G_o$ is simple periodic net annual growth rate of merchantable trees comprising allowable cut (static or slow survivor growth less corresponding mortality; no ingrowth),

$G_1$ is simple periodic net annual growth rate of entire stand over $\underline{m}$ year period (all survivor growth less mortality, plus expected $\underline{m}$ year ingrowth), and

$G_2$ is simple periodic net annual growth rate expected for entire stand over $\underline{n}$ year period, including future $\underline{n}$ year ingrowth anticipated from various sources, such as planting, and net growth stimulation anticipated as a result of future timber stand improvement, (thinning, salvage, and removal of slower-growing items).

H. A. Meyer method (Meyer, Recknagel, Stevenson, 1952)

This is a time-consuming method to apply when detailed data are available. Originally it was designed for all-aged stands but it is applicable to even-aged stands as well. The method involves the calculation of the average number of trees by diameter classes, average volume per tree, average volume per acre, and decadal growth rates for the total area, including all species. The number of trees per acre and volume per acre values must be weighted by the appropriate areas to obtain the correct average values. The decadal growth rates are not weighted. When all these data are available, then a regression equation is calculated, using the logarithm of the number of trees per acre in each diameter class, and de Liocourt's quotient is evaluated, using the equation:

$$N = k\,q^{\frac{-D}{I}}$$

where N is number of trees per acre,

k is constant,

D is diameter at breast height (inch), and

i is diameter class interval (inch) (Sammi, 1961).

The k is calculated from the equation by inserting D = 0 in the exponent. Thus the equation becomes: N = k. Substituting this k value together with an N and a D value calculated from the regression equation, q can be easily obtained as:

$$q = \sqrt[D]{\left(\frac{k}{N}\right)^{i}} \quad .$$

Knowing q and the average growth rates of the diameter classes, the per cent volume increase can be read from a table presented by Meyer, Recknagel and Stevenson (1952, p.159). Multiplying the per cent volume increase by the average volume per acre values, the volume increase by diameter classes can be obtained. By subtracting the average mortality rates from the corresponding volume increase figures and summing up these reduced values, a net volume increase for the total forest can be shown in a table form, similar to Table 33 in Meyer, Recknagel and Stevenson (1952).

Usually when determining the allowable cut, a reduced q is used and a maximum diameter limit is set, beyond which all trees are cut in a certain period of time.

Generally the q is compared to the q of well-managed Swiss forests and reduced accordingly. However, if the present q is lower than that of the Swiss forests, reduction may not become necessary.

## Area and Volume Control Methods

### Area-volume computation

The formulae described above usually give only a guide concerning the quantity of the yearly allowable cut. The West Coast Forest Procedure Committee (1950) recommended that all formula methods should be followed by an area-volume check, described in detail in the report. This check requires knowledge of the areas, stocking, site, and species composition by age classes. If empirical yield tables are used - as in this case - stocking data are not essential.

The procedure begins with the statement of the areas, and the statement of a trial allowable cut figure obtained by one of the methods described previously.

When different type groups are present it is necessary to reduce the areas to a basic type as when area regulation is used.

The next step is to obtain a preliminary estimate of the duration of cut, by dividing the area of the first type or age group by the yearly cutting area. Half of this duration age then is added to the age of the stand when cutting begins, thus obtaining a preliminary estimate of the average cutting age. For this average cutting age the corresponding yield is read from the empirical yield table, and multiplied by the actual number of acres, thus obtaining the total cut in that type. This volume then is divided by the preliminary allowable cut estimate, to see how many years the volume would last in that particular type. This period usually does not coincide with that estimated previously, using the yearly cutting area, and therefore half of the revised duration period must be added to the age of the stand when cutting begins, to obtain a new revised average cutting age.

A new yield per acre based on the revised average cutting age, and multiplied by the actual acres in the type, will give the actual revised yield for the whole type when cut. The final two columns show the duration of the cut per type and cumulative times, assuming that the indicated allowable cut volume will be cut each year.

The next age group or type naturally will have an age, when cutting begins in it, equal to the sum of its present age and the figure shown in the cumulative column.

Otherwise all calculations are the same for this type as have been described for the previous type. At the end of the calculation the final cumulative column must coincide with the rotation age, or must be at least within 5 per cent of the rotation to justify the indicated cutting rate (The Westn. For. and Cons. Assn., 1950). If the difference is more than $\pm$ 5 per cent of the rotation age, the process must be repeated with a higher or lower allowable cut volume, until the calculated rotation age is within the required limit. This figure of allowable cut is used only for the <u>first decade</u> and then the allowable cut is again determined on a basis of data then available.

Naturally this method is highly dependent on the yields per acre read from the empirical yield tables. This can give an erroneous estimate 70 or 80 years hence, particularly for presently immature or recently-planted areas.

Combined method of allotment

This method, as described by Professor Z. Fekete (1950), intends to combine the advantages of the area regulation and the volume regulation in such a way that the yields on nearly similar cutting areas will become close to equal.

In a forest where the distribution of the age classes is fairly even, area regulation and volume regulation give almost the same answer. But, where the age class distribution is irregular, the area regulation might indicate irregular yields, while the volume regulatory methods might indicate irregular cutting areas.

In this case the combined method of allotment may be used. This lessens the irregularity of the yields obtained by the area method and at the same time reduces the differences between the periodic cutting areas.

The combined method starts out from the area regulation with the simplification that the yields are shown only in the first and second cycle. These yields are equalized (averaged) and corresponding areas calculated.

The cuttings of the first cycle proceed according to this plan. Before the beginning of the cuttings in the second cycle another cutting plan must be prepared, equalizing the yields of the second and third cutting cycles. All the other cutting plans are prepared the same way.

The combined method gives a more even periodic yield than the yields obtained by area regulation, and the differences between the periodic cutting areas will also be less than those obtained by volume regulation.

This method reduces the disadvantages of the two methods just mentioned and is a simpler process. Therefore it became a popular regulatory method in central European practice.

The area-volume method calculates with periodic cutting volumes, giving room for some variation in the yearly cuts. It uses volumes available for cut in the immediate future (within two cutting cycles), and reduces the possibility of making undetectable errors for future stand-volume conditions.

## NECESSARY INFORMATION

For trial of the widely different allowable cut calculation methods, a wide variety of data was needed.

In the case of the University Research Forest, much information was available, but this was inadequate because it was in various units of measurement, and taken at different times. Therefore it was decided to undertake a small scale survey to obtain the data in one uniform measurement of wood (cu. ft.) and in such a way that all the necessary information for the formulae and methods mentioned previously could be evaluated.

The headings of the cruise sheets had to be planned to include necessary stand information, and classification standards.

After considering many possibilities, it was decided that a combined method of photo- and ground-cruising would be employed, using the up-to-date photographs of the Research Forest and the point-sampling method, devised by Bitterlich in 1948 and further developed by Grosenbaugh (1952, 1955, 1958).

## DATA COLLECTION AND CALCULATION METHODS

### Classification

Before ground sampling could begin the stratification of forest types had to be completed to provide a good base for the distribution of sample plots. Therefore classification limits were set up and all forest types were sorted into these classes.

The following age classes were established:

| Age Classes | | Limits (years) |
|---|---|---|
| Old Growth | (O.G.) | 160 + |
| Second Growth | (S.G.) | 30 - 159 |
| Young Growth | (Y.G.) | 10 - 29 |
| Planted | (PL.) | 0 - 9 |

#### Forest types

Types were determined according to the order of predominance in the crown closure or volume of a species depending on whether the type was just estimated from photographs or was also visited and sampled on the ground.

A list of all tree species found on the University Forest was given by the U.B.C. Forest Committee (1959). However, in this work only Douglas fir (*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western red cedar (*Thuja plicata* Donn) volumes were considered.

The present study showed that these three species comprise approximately 98 per cent of the total volume in the Research Forest.

To facilitate the later use of empirical yield tables the same type groups were selected as they are shown in the empirical yield tables in Zone 2 (Fligg, 1960), from which the following types were recognized:

| | |
|---|---|
| Douglas fir types | (Growth type 2), |
| Cedar types | (Growth type 5), |
| Hemlock types | (Growth type 7). |

Site classes

Similarly to the forest type classification, the chosen site class limits were identical to those established in Fligg's (1960) Empirical Yield Tables (p.11), separating good G, medium M, poor P and low L sites for different types, and showing the site index limits based on heights at 100 years of age.

Diameter classes

Two-inch diameter classes were chosen, because in most cases this proves satisfactory for management purposes, and eliminates a great deal of extra work.

It is necessary to mention that the estimates made from the photographs or taken on the ground were measured and recorded as accurately as possible, though later they were sorted into the classes described above.

## The Use of Aerial Photographs

### Photo typing

The photographs used were black-and-white, semi-matte in finish, 9 x 9 inches in size, had a representative fraction (R.F.) of 1:15,900, and were taken in June, 1961.

The minimum area in any type was five acres. Types were separated with a black ball point pen using a pocket stereoscope on the basis of the previously stated classification standards.

Ages were not directly estimated from the photographs, but were taken from an age map prepared from previous forest cruises of the area.

The forest types (species composition) were directly estimated from the photographs, using existing forest cover maps as a reference in doubtful cases.

Stand site indices were obtained from two separate estimations, namely: from the age estimation and photographic height measurements.

The latter were carried out for each individual type, measuring the height of one or two trees, representing the average maximum height of the stand (roughly average height of dominant and codominant trees). The site index then was taken from the appropriate B.C. Forest Service site index curves (Fligg, 1960).

### Photographic height measurements

Photographic height measurements of trees were carried out using an Abrams height finder and the most commonly used parallax formula:

$$h = \frac{H\,dp}{P + dp}$$

where h  is height of the tree in feet,

H  is flying height above ground in feet,

dp is parallax difference read from the height finder (mm),

P  is base length as measured from photographs (mm).

To speed up measurement a combined graphical solution of the parallax formula was used which corrected the errors resulting from the tree's being on an elevation different than the average height of the two principal points:

First, basic lines were calculated for each different P value measured from the photographs from which the equivalent height in feet for one mm. parallax difference could be read. The equation of these lines was:

$$hp = H \frac{0.01}{P + 0.01}$$

where hp is height in feet at elevation of average value of the principal points (ft.),

H  is flying height (ft.), and

P  is average length of the principal points (mm.).

The calculation was carried out only for two different flying heights, because the equation above indicates a straight line, for which two points are adequate.

The next step was to construct the correction lines by calculating the parallax differences, which occur when trees are higher or lower than average elevation of the principal points.

For this purpose the equation used was:

$$dp = \frac{Ph}{H - h}$$

where dp is parallax difference between the base of the tree and the average height of the two principal points (mm.),

P is average base length between principal points (mm.),

H is average height of the two principal points (ft.), and

h is elevation difference between the average height of the principal points and the base of the tree (mm.).

When different values of $h$ were substituted in the equation a slightly curved line resulted.

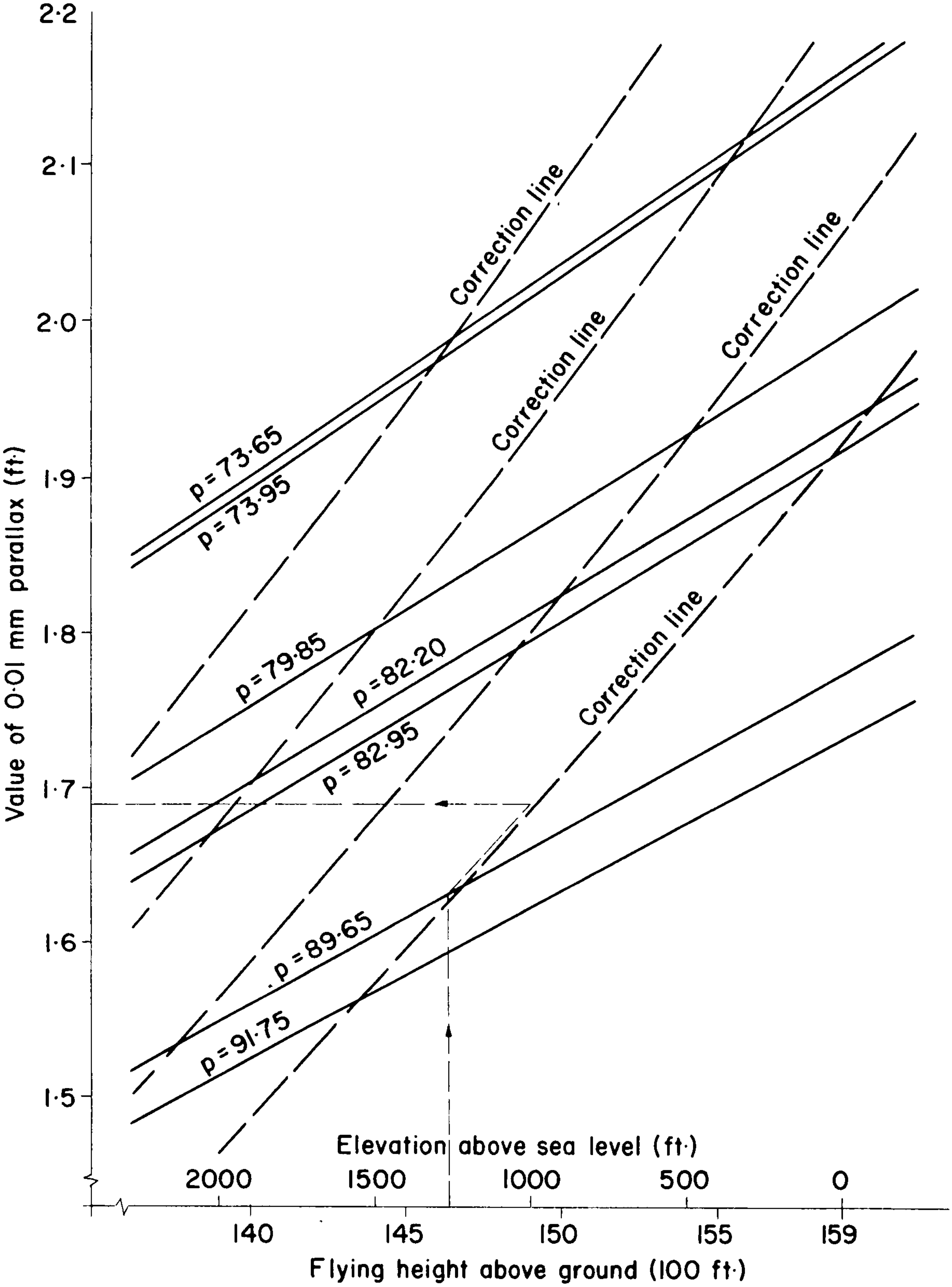
These correction lines were plotted on the same graph, showing the height corrections in feet for differences in elevation.

To obtain a tree height the steps outlined below were followed:

1. Calculate average base length of the stereo pair.
2. Calculate average flying height above principal points.
3. Obtain elevation of the tree base.
4. Measure parallax difference of tree.
5. Find average flying height $H$ on the $x$ axis of the graph. From that point go perpendicular until the line of the average base length is met. (From this point the correction lines must be followed parallel, until the corresponding vertical line marking the elevation of

Graphical solution of the parallax formula

Figure 3·



the tree base is hit.) At this point the correct value of the 0.01 mm. parallax can be read from the y axis. For example, P = 89.65 mm., H = 14,640 ft., elevation of the tree base 1,000 ft., then the 0.01 mm. parallax difference corresponds to 1.690 ft. on the ground. Multiplying the value read from the y axis by the total parallax difference read from the height finder gives the total height of the tree (Figure 3).

Area determination

Although the total area of the Forest was known (9,774 ac.), a detailed area determination was necessary for each individual type, to furnish the base for stand-table projection, and for the allocation of future cutting areas.

It was decided to use the grid area-determination system described in Spurr (1960), combined with a correction method suitable for mountainous areas.

The calculation of the number of points necessary to give a desired accuracy was given by Spurr (1960).

$$N = \frac{P\ (1 - P)\ (t^2)}{Ep^2} \quad ;$$

where N is number of points necessary,

P is per cent of class limit of the total area,

Ep is error per cent of class limit, and

t is statistical constant.

Using the values of the 5 acre class limit:

$$P = \frac{5}{9774} \times 100 = 0.0512,$$

$$Ep = 0.009, \text{ and } t = 1.96,$$

$$N = \frac{0.0512\ (1 - 0.0512)\ (1.96)^2}{(0.009)^2} = 2{,}351 \text{ points at sea level.}$$

The distance in inches of these points on the photograph when distributed evenly is:

$$Dp = \frac{\left(\sqrt{\dfrac{(9{,}774)\ (43{,}560)}{2{,}351}}\right)\ 12}{15{,}900} = 0.321 \text{ inches.}$$

Rounding this distance to 0.300 inches and recalculating Ep and N, we obtain 0.0083 per cent and 2,694 points respectively.

Since the photographs were taken over mountainous terrain, it was necessary to weight the areas represented by these points by elevation. For example, because of scale differences, a point appearing at 2,000 feet elevation will represent a much smaller area than one appearing on sea level, assuming the spacing of these points is even.

Reduction factors were calculated using the equation:

$$W = \left(1 - \frac{EL}{15{,}900}\right)^2$$

where W is weight of the plot, and

EL is elevation in feet.

TABLE 1

WEIGHTS OF POINTS BY ELEVATION LIMITS

| Elevation Limits (ft.) | Weights |
|---|---|
| 0 - 200 | 0.9875 |
| 201 - 600 | 0.951 |
| 601 - 1,000 | 0.902 |
| 1,001 - 1,400 | 0.855 |
| 1,401 - 1,800 | 0.809 |
| 1,801 - 2,200 | 0.764 |
| 2,201 - 2,600 | 0.721 |

The evenly-spaced points were pricked on the photographs and a transparent overlay was prepared showing the elevation limits.

Counting the number of points falling into a type multiplied by the corresponding weight gave the number of points which would have fallen into that type if it were at sea level.

The influence of sloping terrain became evident when the final total reduced number of points was counted and compared to the calculated number of points at sea level. A discrepancy of -3.12 per cent of the total area resulted and had to be distributed proportionally to the individual types. This underestimate is due to the steep sloping terrain on many parts of the Research Forest, especially the so-called "Pitt Lake slope". (Corrected areas are shown in Tables 3 and 6.)

A brief comparison of the areas shown in 1958 to the present condition was based on the data published by the University Forest Committee (1959).

TABLE 2

COMPARISON OF AREAS AS ESTIMATED IN 1958 AND IN 1961.

| Class | 1958 (ac.) | 1961 (ac.) | Difference based on 1958 (ac.) |
|---|---|---|---|
| Productive land | 9,100 | 9,282 | 182 |
| Road | 80 | 48 | - 32 |
| Rock | 180 | 30 | - 150 |
| Water | 313 | 340 | 27 |
| Swamp | 90 | 57 | - 33 |
| Urban | 11 | 17 | 6 |
| TOTAL | 9,774 | 9,774 | |

Considerable differences between the two area estimates are present. The reason of these discrepancies can be explained mainly by the actual changes in the areas (e.g. urban) and partly by the sampling approach of the point-grid area-estimation method. However, other facts which may cause large differences between the two estimates must also be mentioned. In the present method, some of the areas which were classified as rock and poor and rocky on the Abernethy and Lougheed (A.&L.) part of the forest were classified as poor stocking and listed in the productive land area. Also, it should not be forgotten that since 1958 the vegetation might have covered a large part of these small rocky areas, therefore many of these small rock outcrops may have appeared on the 1961 photos as productive sites.

TABLE 3

AREA SUMMARY FOR THE UNIVERSITY RESEARCH FOREST

| TYPE | East Side (Y.G.) * | West Side (O.G., S.G.) * | Total Forest |
|---|---|---|---|
| | AREA (ACRES) | | |
| Stocked | 3,793 | 5,489 | 9,282 |
| Road | 29 | 19 | 48 |
| Rock | 7 | 23 | 30 |
| Water | 46 | 294 | 340 |
| Swamp | 42 | 15 | 57 |
| Urban | --- | 17 | 17 |
| TOTAL | 3,917 | 5,857 | 9,774 |

* Y.G. stands average 25 years in age; S.G. stands average 80 years, and O.G. stands are more than 300 years old.

The differences in the water and swamp classes may be due to the season when the measurements were made. Hence, in one case, swamps could have been classified as water, while in a drier part of the year they obviously appear as swamps, and could have been sorted into the swamp class. Note that only 6 acres difference appears between the sum of water and swamp classes between the two measurements (1958 and 1961).

Another comparison of the areas in the productive class is shown below:

TABLE 4

COMPARISON OF PRODUCTIVE AREAS AS ESTIMATED IN 1958 AND IN 1961

| Type | 1958 (ac.) | 1961 (ac.) | Difference from 1958 (ac.) |
|---|---|---|---|
| * O.G. | 916 | 994 | + 78 |
| S.G. and scattered O.G. | 3,162 | 3,701 | + 539 |
| Y.G. P. | 3,340 | 3,676 | + 336 |
| Planted and cultivated | 440 | 558 | + 118 |
| Hardwood and scrub | 1,242 | 353 | - 889 |
| TOTAL | 9,100 | 9,282 | |

* About 250 acres of old growth (O.G.) were logged 1958-1961.

The largest discrepancy is in the scrub type, and is caused by the extreme overestimation of scrubby areas in 1958, on the Pitt Lake slope and on the A.&L. part of the Forest.

The recent estimates, however, show that no such large acreage of scrub exists on these areas. On the Pitt Lake slope there are mostly well growing, satisfactorily stocked stands of low site quality, leaving just a small area for scrub and several stands of alder and maple.

No definite evaluation has been made regarding productive stands of the A.&L. part of the Forest, since only the areas of the following classes were estimated by the writer:

Total area, Stocked, Road, Rock, Water, and Swamps.

Detailed area estimates of the stocked classes in the A.&L. part of the Forest as shown by Bajzak (1960), were proportionally distributed to the recent estimate of the stocked area.

## The Use of McBee Punch Cards

The individual measurements of the types were recorded on McBee punch cards for easier selection. The card was divided into columns where the number of the type, estimated crown closure, species composition, etc. were recorded.

The actual order of numbers and headings on a McBee card appeared as follows:

| Photo number | Type number | Crown closure | Species composition | Date of establishment | Height | History | Area | S.I. | S.I. code |
|---|---|---|---|---|---|---|---|---|---|

The descriptions of the items are as follows:

Photo number: Gives the number of photograph on which the type represented by a type number (second column) appears.

Crown closure: Is a number which shows the area covered by the crowns in relation to the total area, in 10 per cent units.

Species composition symbols are similar to those appearing in the empirical yield tables.

Date of establishment marks the century and decade in which the stand was regenerated. For example, a stand regenerated in 1860 will have a date of establishment "86".

Height of the stand in feet appears as it was measured on the photographs.

History: A sign indicates the cause responsible for re-establishment. Thus $\ominus$ designates clear cutting, ⦶ designates fire, and $\overset{\wedge}{\ominus}$ designates selective cutting. The combination of these signs can also appear.

Area of the type is shown in acres.

Site index is shown as taken from the corresponding B.C. Forest Service site index curves. For example, in a type having a species composition of FH (Douglas fir-hemlock), the site index appearing was taken from the Douglas fir site index curve, but where HC (hemlock-cedar) or CH type was present, the site index was taken from the HC site index curve.

Site indices taken from the various site index curves were not considered adequate for some calculations. Therefore a site index code was established for reducing site indices to the same level. This was done using the B.C. Forest Service Site Index curves, which show that the limits of the site index classes are higher by 10 feet for Douglas fir, than for hemlock and cedar. Thus:

The site index code for Douglas fir types = (S.I. - 20) 0.025

The site index code for hemlock and cedar types = (S.I. - 10) 0.025.

After the substitution of the various site indices into the appropriate equation above, the calculated code gave the equivalent ranges of the site classes in the same units. Thus the site indices regardless of species became equivalent to the codes shown as follows:

TABLE 5

SITE INDICES AND CORRESPONDING CODES

| Site classes | S.I. Limits (ft.) Douglas fir | Hemlock and Cedar | Codes |
|---|---|---|---|
| Low | 0 - 60 | 0 - 50 | 0 - 1.0 |
| Poor | 61 - 100 | 51 - 90 | 1.1 - 2.0 |
| Medium | 101 - 140 | 91 - 130 | 2.1 - 3.0 |
| Good | 141 + | 131 + | 3.1 + |

Example: If a medium site land bearing a Douglas fir stand shows a site index of 130, the same land, bearing a hemlock stand, would show only a 120 site index. Using a code, both stands would have a 2.75 code, indicating a medium site quality regardless of species. Naturally the codes can be easily reversed to either Douglas fir or hemlock site index values, by rearranging the equations above. These values were then available for use with the empirical yield tables and for converting cover types to the FH medium site standard. Also, using these reduced values, the calculations of the weighted average site index for the types and for the whole of the Forest were easily carried out, by converting the average codes to Douglas fir site index values.

The summary of the average ages and site indices is shown in Table 6.

TABLE 6

AREAS, SITE INDICES, AVERAGE AGES, GROSS CU. FT. VOLUMES BY MINIMUM DIAMETER CLASSES, AND SPECIES COMPOSITIONS BY AGE AND SITE CLASSES

| * Class | | MIN. D.B.H. LIMIT (in.) | O.G.G. | O.G.M. | O.G.P. | S.G.G. | S.G.M. | S.G.P. |
|---|---|---|---|---|---|---|---|---|
| AREA | (ac.) | | 159 | 671 | 164 | 805 | 1885 | 968 |
| S.I. (F) | (ft.) | | 161 | 117 | 76 | 161 | 121 | 83 |
| AVG. AGE | (yrs.) | | 230 | 260 | 240 | 70 | 80 | 90 |
| GROSS VOLUME (CU.FT.) | | 3.1 | 2,197,062 | 9,200,752 | 1,587,028 | 7,430,150 | 20,587,970 | 6,578,528 |
| | | 9.1 | 2,161,923 | 8,928,997 | 1,483,544 | 6,802,250 | 17,984,785 | 3,554,496 |
| | | 11.1 | 2,145,387 | 8,852,503 | 1,406,792 | 6,206,550 | 10,599,310 | 2,269,960 |
| | | 13.1 | 2,136,006 | 8,694,818 | 1,296,092 | 5,535,180 | 14,446,640 | 1,466,520 |
| Species Composition | | | HF | CH | CH | FH | FH | HF |

| Class | | MIN. D.B.H. LIMIT (in.) | S.G.L. | Y.G.G. | Y.G.M. | Y.G.P. | PL. | HW. |
|---|---|---|---|---|---|---|---|---|
| AREA | (ac.) | | 43 | 2170 | 1171 | 335 | 558 | 353 |
| S.I. (F) | (ft.) | | 50 | 135 | 125 | 85 | 134 | 113 |
| AVG. AGE | (yrs.) | | 90 | 30 | 25 | 20 | 5 | 40 |
| GROSS VOLUME (CU. FT.) | | 3.1 | 208,034 | 2,444,288 | 238,685 | 5,236 | --- | --- |
| | | 9.1 | --- | 968,666 | 49,861 | 12,737 | --- | --- |
| | | 11.1 | --- | 561,856 | 19,333 | 3,645 | --- | --- |
| | | 13.1 | --- | 304,429 | 11,452 | --- | --- | --- |
| Species Composition | | | FH | HC | HC | CH | F | - |

* Abbreviations of classes are explained on pages 44 and 45.

## Ground Sampling

It was decided that probability (point) sampling techniques would be used for determination of the number of trees per acre, diameter growth, and bark thickness values in different types.

Only 98 point samples were distributed to the different strata. In addition to these, the existing permanent sample points and temporary plots from the A.&L. part of the Research Forest (Bajzak, 1960) were used to furnish the required data for the stand table projection purposes.

The numbers of those types sampled were selected using a random number table. The sample centre points were located measuring full chain lengths from a clearly distinguishable point visible on the photograph, falling in or close to the type. The bias from personal judgement was thus eliminated, and reasonable randomness in the location of the sample points was achieved.

For the determination of trees falling into the sample, and tree height measurements, the Austrian-made Spiegel relascope was used. It was found to be a very convenient, accurate and handy instrument, although the optical distance measurement in old growth stands was not very practical.

For checking "border trees", Stage's (1959) cruising computer was used, which was also found convenient for the rapid calculation of tree heights.

The role of the Spiegel relascope in the sampling was simply to determine the trees which had to be measured. Then the diameter of the selected trees was measured with a diameter tape, and recorded to the nearest tenth of an inch. All trees larger than 3.0 inches at breast height were measured.

For age, diameter growth, and bark thickness determinations, increment borers were used. Every fourth tree in the plot was bored. Measurements were recorded to the nearest hundredth of an inch, for both the increment core lengths and bark thicknesses.

Decayed, or partly-living boles (as was common on cedars) were not bored.

The following headings were used on the tally sheet:

Type No.: B.A. Factor: Date:

| Spec. | D.B.H. | Cond. class | Crown class | Double bark thickness | 10 yrs. growth | 20 yrs. growth | Age at B.H. | Height |
|---|---|---|---|---|---|---|---|---|

Species symbols used in the inventory are listed below:

| Symbol | Species |
|---|---|
| F | Douglas fir |
| H | Western hemlock, or hemlock |
| C | Western red cedar, or cedar |
| Cy | Yellow cedar |
| B | Abies species |
| D | Red alder |
| Pl | Lodgepole pine |
| Pw | White pine |

Under the heading of condition class (cond.class) the following were recorded:

1 living tree,

2 a dead tree (died within the last five years).

Trees that died before 1956 were not included in the cruising.

Four different crown classes were also distinguished as:

1 dominant,

2 codominant,

3 intermediate,

4 suppressed.

Heights (Ht.) were measured to the nearest foot.

It may be of interest to note the reliability of photo estimates and compare them with the results obtained by the ground measurements.

Species composition estimates were correctly recorded (falling within the same type group) 88 per cent of the time, while age class determinations were 91 per cent correct in comparison with the ground checked types. Height measurements, however, in most cases showed a great variation on the photographs as well as on the ground. Naturally, ground estimates, in a stand with widely variable heights, taken from an inadequate number of samples, cannot be considered as a sufficient base for comparison. Photo estimates of average stand heights in this situation should provide a more reliable, but slightly conservative, source of information for stand site index calculation purposes.

In this particular case, after ground checking, the measurements taken from the aerial photographs were corrected and used for site index determination.

Calculations

Having finished the photo and ground sampling, the necessary calculations for the stand table projection process had to be carried out. The method of the stand table projection was that described in detail by W. H. Meyer (1952). The required data are:

Number of trees per acre,

Mortality ratios, and

Periodic diameter growth by diameter classes.

The stand table projections were carried out only for the main species, namely, Douglas fir, hemlock, and cedar.

Method of Calculating the Number of Trees per Acre, and Mortality Rates

Because some of the allowable cut methods required separate data by age, site, and condition classes, it became necessary to select trees by species for the following age and site classes:

| | |
|---|---|
| Old growth, good site | (O.G.G.) |
| Old growth, medium site | (O.G.M.) |
| Old growth, poor site | (O.G.P.) |
| Second growth, good site | (S.G.G.) |
| Second growth, medium site | (S.G.M.) |
| Second growth, poor site | (S.G.P.) |

| | |
|---|---|
| Second growth, low site | (S.G.L.) |
| Planted | (PL.) |
| Hardwood | (HW.) |

Although in the young growth (Y.G.) stands the data given by Bajzak (1960) were not similar to the site classes required for this work, his good, medium and poor stocking classes could be fitted into the present site classification. His nomenclature has been kept, but it should be noted that it means stocking classes here, and not site classes.

| | |
|---|---|
| Young growth, good | (Y.G.G.) |
| Young growth, medium | (Y.G.M.) |
| Young growth, poor | (Y.G.P.) |

Prior to computer calculations on the Alwac III-E all data for the computation of the number of trees and for further sorting had to be transferred to numerical symbols.

Species codes Fir (1), H (2), C (3) , diameter at breast height in inches, codes defining whether the tree was alive (1), or had died within the last five years (2), and the horizontal point factor (H.P.F.) which is equal to 183.346 times basal area factor (Grosenbaugh, 1958, p.16), were typed, starting with the species code in each line.

Simultaneously, these data were automatically punched on a tape to make the data readable for the machine. When calculating, the computer took in a row of data and executed the following equation:

$$N = \frac{H.P.F.}{D^2}$$

where N is number of trees per acre,

H.P.F. is horizontal point factor, and

D is diameter at breast height.

The theoretical base of these calculations is inherent to the point sampling theory:

"It must be remembered that point-sampled trees are not sampled proportionally to their frequency as plot-sampling would do. Hence, their basal areas, volumes, frequency, etc. should not be given the same equal weight as in plot-sampling. Instead, before any further calculations are made, each point-sampled tree should have its basal area, volume, frequency, etc. weighted inversely as its probability of being sampled. Dividing each sample-tree basal area, volume or frequency by its own basal area does this." (Grosenbaugh, 1955, p.19.)

Finally, "blow up" factors or multipliers are needed to convert point sample ratios to a per acre basis. The horizontal point factor (H.P.F.) assumes that the denominators of the ratios will be tree diameters in square inches. (This constant is called basal area factor, when denominators of the ratios are tree basal areas in square feet.)

After computer calculation of the number-of-trees-per-acre value, the sorting of the different tree species into 2-inch diameter classes was carried out. The summation of the number-of-trees-per-acre values falling into the same diameter class within a type group was done by hand, as well as other calculations after this point.

To obtain the final value of the number of trees in a diameter class for an age and site class, the sum obtained this way had to be divided by the number of point samples falling into that type group. In a similar way the number of trees per acre that died within the last five years was calculated. These latter values had to be multiplied by two, to obtain ten-year mortality. From these two number-of-trees-per-acre values, mortality ratios were easy to get, by dividing the number of dead trees per acre by the number of living trees per acre. These values appear in Tables 8, 9 and 10.

Some indication of the variability of the mortality estimates can be given by showing the minimum and maximum estimates of number-of-trees-per-acre mortality during the past decade, in the various forest type classes.

For Douglas fir, hemlock and cedar species, mortality ranges per acre by forest type classes are presented as follows:

TABLE 7

MINIMUM AND MAXIMUM NUMBER OF DEAD TREES PER ACRE

BY SPECIES AND TYPE CLASSES

| Type | No. of dead trees per acre | | | | | | Number of plots or sample points |
|---|---|---|---|---|---|---|---|
| | Minimum | | | Maximum | | | |
| | F | H | C | F | H | C | |
| O.G.G. | 0 | 0 | 0 | 3.87 | 216.51 | 65.19 | 14 |
| O.G.M. | 0 | 0 | 0 | 4.61 | 482.17 | 358.10 | 33 |
| O.G.P. | 0 | 0 | 0 | 0 | 255.52 | 40.63 | 13 |
| *S.G.G. | 2.3 | 3.1 | 6.8 | 28.2 | 87.50 | 62.50 | 5 |
| *S.G.M. | 0 | 2.3 | 0 | 61.50 | 84.10 | 50.00 | 15 |
| *S.G.P. | 2.1 | 50.0 | 2.5 | 30.00 | 87.50 | 17.50 | 3 |
| Y.G.G. | 0 | 0 | 0 | 0 | 126.88 | 0 | 100 |
| Y.G.M. | 0 | 0 | 0 | 0 | 83.86 | 0 | 96 |
| Y.G.P. | 0 | 0 | 0 | 0 | 0 | 0 | 72 |

* Data taken from permanent sample plots.

The values clearly indicate that hemlock has the largest mortality range among the species considered. In the old growth stands this mortality was concentrated on the smaller diameter trees (approximately 0 - 16 inches). The mortality of the Douglas fir was low in all stands.

It must be noted that in the second growth stands, as well as in the young growth stands, about 80 per cent of the existing white pines died within the last five years, and the few remaining living trees appear to be unhealthy or dying.

TABLE 8

NUMBER OF TREES PER ACRE (NT) AND 10-YEAR MORTALITY RATES (MR) BY AGE AND SITE CLASSES FOR DOUGLAS FIR

| D.B.H. | O.G.G. | | O.G.M. | | O.G.P. | | S.G.G. | | S.G.M. | | S.G.P. | | S.G.L. | | Y.G.G. | | Y.G.M. | | Y.G.P. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| in. | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR |
| 4 | | | | | | | | | | | | 0.47 | 895.28 | - | 7.11 | - | 7.05 | - | 4.17 | - |
| 6 | | | | | | | | | 6.27 | 0.45 | 8.05 | 0.23 | 231.45 | - | 5.24 | - | 5.00 | - | 2.92 | - |
| 8 | | | | | | | 13.16 | 0.56 | 3.18 | 0.17 | 10.35 | 0.11 | 162.14 | - | 3.09 | - | 0.79 | - | 2.08 | - |
| 10 | | | | | | | | 0.01 | 10.22 | 0.06 | 16.03 | 0.04 | - | - | 2.55 | - | 1.05 | - | 0.42 | - |
| 12 | | | | | | | 11.20 | 0.21 | 3.99 | 0.03 | 4.59 | - | - | - | 2.01 | - | 0.26 | - | 0.42 | - |
| 14 | 1.26 | - | - | - | - | - | 2.52 | 0.01 | 10.09 | 0.02 | 11.07 | - | - | - | 0.81 | - | 0.26 | | | |
| 16 | | | | | | | 2.81 | - | 14.56 | 0.04 | - | - | - | - | 0.13 | | | | | |
| 18 | | | | | 0.91 | - | 5.39 | 0.20 | 5.82 | - | 2.08 | - | - | - | 0.13 | | | | | |
| 20 | 1.92 | - | 0.53 | - | 0.75 | - | 1.06 | - | 2.51 | - | 1.77 | - | - | - | 0.13 | | | | | |
| 22 | | | | | | | 8.35 | - | 1.27 | | | | | | | | | | | |
| 24 | 0.47 | - | - | - | 0.52 | - | 0.84 | - | 3.96 | | | | | | | | | | | |
| 26 | 0.41 | - | 0.48 | - | 0.81 | - | 1.29 | - | 0.60 | | | | | | | | | | | |
| 28 | 0.62 | - | 0.29 | 0.14 | 0.38 | - | 1.20 | | | | | | | | | | | | | |
| 30 | 1.16 | 0.28 | 0.51 | - | 0.92 | - | 2.05 | - | 0.22 | | | | | | | | | | | |
| 32 | 1.01 | - | 0.22 | - | - | - | 1.37 | - | 0.20 | | | | | | | | | | | |
| 34 | 1.36 | - | 0.39 | - | 0.23 | - | 1.53 | | | | | | | | | | | | | |
| 36 | 0.62 | - | 0.17 | - | - | - | 0.35 | | | | | | | | | | | | | |
| 38 | 0.19 | - | - | 0.15 | - | - | 0.33 | | | | | | | | | | | | | |
| 40 | 1.94 | - | 0.41 | - | - | - | 0.84 | - | 0.13 | | | | | | | | | | | |
| 42 | 0.95 | - | - | - | - | - | - | - | 0.12 | | | | | | | | | | | |
| 44 | 0.40 | - | 0.28 | | | | | | | | | | | | | | | | | |
| 46 | 0.31 | - | 0.11 | | | | | | | | | | | | | | | | | |
| 48 | 0.18 | - | 0.05 | - | - | - | - | - | 0.09 | | | | | | | | | | | |
| 50 | 0.31 | - | 0.05 | | | | | | | | | | | | | | | | | |
| 52 | 0.15 | - | 0.04 | - | - | - | - | - | 0.07 | | | | | | | | | | | |
| 54 | 0.09 | - | - | - | - | - | - | - | 0.07 | | | | | | | | | | | |
| 56 | 0.10 | - | 0.04 | - | - | - | - | - | 0.06 | | | | | | | | | | | |
| 58 | 0.27 | - | 0.10 | | | | | | | | | | | | | | | | | |
| 60 | 0.33 | | | | | | | | | | | | | | | | | | | |
| 62 | 0.07 | | | | | | | | | | | | | | | | | | | |
| 64 | 0.20 | | | | | | | | | | | | | | | | | | | |
| 66 | 0.18 | | | | | | | | | | | | | | | | | | | |
| 68 | | | | | | | | | | | | | | | | | | | | |
| 70 | 0.10 | - | 0.05 | | | | | | | | | | | | | | | | | |
| 72 | | | | | | | | | | | | | | | | | | | | |
| 74 | 0.05 | | | | | | | | | | | | | | | | | | | |
| 76 | | | | | | | | | | | | | | | | | | | | |
| 78 | | | | | | | | | | | | | | | | | | | | |
| 90 | | | | | | | | | | | | | | | | | | | | |

TABLE 9

NUMBER OF TREES PER ACRE (NT) AND 10-YEAR MORTALITY RATES (MR) BY AGE AND SITE CLASSES FOR WESTERN HEMLOCK

| D.B.H. | O.G.G. | | O.G.M. | | O.G.P. | | S.G.G. | | S.G.M. | | S.G.P. | | S.G.L. | | Y.G.G. | | Y.G.M. | | Y.G.P. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| in. | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR |
| 4 | 6.69 | 1.00 | 64.80 | 0.31 | 172.02 | 0.10 | - | 0.62 | 61.23 | 0.34 | 196.50 | 0.39 | - | - | 63.80 | 0.07 | 21.85 | 0.02 | 11.67 | 0.05 |
| 6 | 18.29 | - | 26.60 | 0.14 | 17.38 | - | 12.32 | 0.20 | 57.45 | 0.13 | 117.25 | 0.22 | - | - | 30.10 | 0.14 | 3.03 | 0.06 | 4.17 | 0.09 |
| 8 | 3.99 | - | 14.54 | - | 13.05 | - | 30.06 | 0.30 | 22.24 | 0.04 | 79.04 | 0.07 | - | - | 14.27 | - | 2.46 | - | 0.42 | - |
| 10 | 5.14 | - | 5.70 | - | 21.32 | 0.12 | 17.72 | 0.08 | 16.00 | - | 37.60 | 0.01 | - | - | 6.58 | 0.12 | | | | |
| 12 | 2.13 | 1.00 | 6.36 | 0.10 | 5.92 | 0.34 | 10.74 | - | 27.16 | - | 18.71 | 0.17 | - | - | 1.88 | | | | | |
| 14 | 6.82 | 0.37 | 5.43 | - | 5.52 | 0.55 | 5.84 | - | 12.79 | - | 9.08 | - | - | - | 0.81 | | | | | |
| 16 | 6.50 | - | 3.31 | - | 9.17 | - | 3.58 | - | 6.51 | - | 2.35 | - | - | - | 0.26 | | | | | |
| 18 | 4.81 | - | 4.05 | - | 6.07 | 0.14 | - | - | 3.21 | - | - | - | - | - | 0.13 | | | | | |
| 20 | 2.66 | - | 1.91 | - | 3.91 | - | - | - | 2.93 | | | | | | | | | | | |
| 22 | 1.66 | - | 3.48 | 0.07 | 2.36 | 0.23 | - | - | 0.40 | | | | | | | | | | | |
| 24 | 0.24 | - | 3.22 | - | 0.92 | - | 0.76 | - | 0.71 | | | | | | | | | | | |
| 26 | 0.22 | - | 2.27 | 0.07 | 0.82 | - | 1.68 | - | - | - | 0.49 | | | | | | | | | |
| 28 | 1.55 | 0.10 | 1.81 | - | 1.42 | - | 0.29 | - | - | - | 0.43 | | | | | | | | | |
| 30 | 0.58 | - | 0.84 | - | 0.61 | - | 0.26 | | | | | | | | | | | | | |
| 32 | 0.27 | - | 1.40 | 0.07 | 0.28 | | | | | | | | | | | | | | | |
| 34 | 1.16 | - | 0.58 | 0.47 | 0.73 | | | | | | | | | | | | | | | |
| 36 | 0.51 | - | 0.43 | 0.42 | | | | | | | | | | | | | | | | |
| 38 | 0.47 | - | 0.38 | 0.21 | | | | | | | | | | | | | | | | |
| 40 | 0.67 | - | 0.21 | - | 0.17 | - | - | - | 0.12 | | | | | | | | | | | |
| 42 | 0.61 | - | 0.19 | | | | | | | | | | | | | | | | | |
| 44 | 0.54 | - | 0.35 | | | | | | | | | | | | | | | | | |
| 46 | 0.13 | - | 0.11 | | | | | | | | | | | | | | | | | |
| 48 | 0.34 | - | - | - | 0.12 | | | | | | | | | | | | | | | |

TABLE 10

NUMBER OF TREES PER ACRE (NT) AND 10-YEAR MORTALITY RATES (MR) BY AGE AND SITE CLASSES FOR WESTERN RED CEDAR

| D.B.H. | O.G.G. | | O.G.M. | | O.G.P. | | S.G.G. | | S.G.M. | | S.G.P. | | S.G.L. | | Y.G.G. | | Y.G.M. | | Y.G.P. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| in. | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR | NT | MR |
| 4 | | | | | 14.51 | - | - | - | 110.40 | 0.17 | 146.77 | 0.19 | 241.70 | - | 56.40 | - | 14.74 | - | 9.58 | - |
| 6 | 5.35 | - | - | - | 5.92 | - | 25.33 | 0.28 | 56.59 | 0.09 | 57.29 | 0.31 | - | - | 21.90 | - | 2.63 | - | 4.58 | - |
| 8 | - | 1.00 | 10.11 | - | 20.95 | - | 14.71 | 0.21 | 19.26 | 0.02 | 49.50 | - | - | - | 7.11 | - | 0.80 | - | 1.25 | - |
| 10 | 1.35 | - | 1.31 | 0.27 | 8.14 | 0.38 | 27.01 | - | 13.33 | 0.02 | 23.68 | - | - | - | 2.95 | - | 0.53 | - | 1.25 | - |
| 12 | - | - | 2.78 | - | 23.87 | 0.17 | 7.90 | - | 7.30 | - | 9.33 | - | - | - | 0.94 | | | | | |
| 14 | 1.50 | - | 5.50 | - | 10.31 | - | 2.33 | - | 3.93 | - | 2.51 | - | - | - | 0.40 | | | | | |
| 16 | 1.81 | - | 2.65 | 0.31 | 15.15 | - | 3.74 | - | 5.72 | - | 1.17 | - | - | - | 0.27 | | | | | |
| 18 | - | - | 5.08 | 0.14 | 7.56 | - | 3.05 | - | 5.45 | | | | | | | | | | | |
| 20 | - | - | 2.79 | - | 11.26 | - | 0.57 | - | 1.65 | - | 0.89 | | | | | | | | | |
| 22 | 1.43 | 0.36 | 2.26 | - | 5.26 | - | 0.92 | - | 2.07 | - | 0.66 | | | | | | | | | |
| 24 | 0.23 | - | 2.16 | - | 2.46 | - | - | - | 1.05 | - | 0.59 | | | | | | | | | |
| 26 | 1.53 | 0.13 | 3.55 | - | 2.47 | - | - | - | 0.63 | | | | | | | | | | | |
| 28 | 0.18 | - | 4.65 | - | - | 1.00 | - | - | 0.52 | | | | | | | | | | | |
| 30 | 0.28 | 0.54 | 2.47 | - | 1.25 | - | - | - | 0.78 | | | | | | | | | | | |
| 32 | 0.13 | - | 3.31 | 0.03 | 0.28 | | | | | | | | | | | | | | | |
| 34 | 0.78 | - | 2.13 | - | 0.73 | - | - | - | 0.18 | | | | | | | | | | | |
| 36 | 0.60 | - | 1.89 | - | 0.22 | - | - | - | 0.15 | | | | | | | | | | | |
| 38 | 0.81 | - | 1.00 | - | 0.19 | - | - | - | 0.15 | | | | | | | | | | | |
| 40 | 0.67 | - | 1.26 | - | - | - | - | - | 0.12 | | | | | | | | | | | |
| 42 | 0.51 | - | 0.85 | - | - | - | - | - | 0.12 | | | | | | | | | | | |
| 44 | 0.28 | - | 0.36 | - | - | - | - | - | 0.11 | | | | | | | | | | | |
| 46 | 0.55 | - | 0.42 | | | | | | | | | | | | | | | | | |
| 48 | 0.23 | 0.96 | 0.53 | - | - | - | - | - | 0.09 | | | | | | | | | | | |
| 50 | 0.16 | - | 0.09 | - | - | - | 0.57 | - | 0.08 | | | | | | | | | | | |
| 52 | 0.35 | - | 0.12 | - | 0.10 | | | | | | | | | | | | | | | |
| 54 | 0.18 | - | 0.15 | - | - | - | 0.16 | - | 0.07 | | | | | | | | | | | |
| 56 | 0.09 | - | 0.14 | - | - | - | - | - | 0.07 | | | | | | | | | | | |
| 58 | 0.20 | - | 0.07 | 0.43 | - | - | - | - | 0.06 | | | | | | | | | | | |
| 60 | 0.18 | - | 0.12 | | | | | | | | | | | | | | | | | |
| 62 | 0.07 | | | | | | | | | | | | | | | | | | | |
| 64 | 0.25 | | | | | | | | | | | | | | | | | | | |
| 66 | 0.12 | | | | | | | | | | | | | | | | | | | |
| 68 | 0.06 | - | 0.02 | | | | | | | | | | | | | | | | | |
| 70 | - | | | | | | | | | | | | | | | | | | | |
| 72 | - | - | 0.02 | | | | | | | | | | | | | | | | | |
| 74 | - | | | | | | | | | | | | | | | | | | | |
| 76 | - | | | | | | | | | | | | | | | | | | | |
| 78 | 0.04 | - | - | - | - | - | - | - | 0.03 | | | | | | | | | | | |
| 94 | - | - | 0.01 | | | | | | | | | | | | | | | | | |

For the A.&L. part of the forest the number of trees per acre of the good, medium and poor stocked types were taken from Bajzak's thesis (1960). The mortality rates were based on a mortality cruise carried out by the author during the summer of 1961. Mortality rates for the second-growth stands obtained from point samples were not used; instead, data available from permanent sample measurements were employed. Since permanent sample plots covered a wide range of site classes within the second growth type, a selection of the plots had to be carried out, to sort these plots into the presently used site classes. After sorting, the required mortality rates (M.R.) were obtained from the corresponding age and site groups of the present classification and substituted for the incomplete mortality estimates of the recent cruising.

Method of Calculating Future Decadal Diameter Growth

Giving consideration to a number of assumptions, finally the method which assumes linear growth rate in basal area was accepted. This growth calculation method was not previously used because of the large number of calculations required, but with the ALWAC III-E electronic computer, the method can be used successfully.

The derivation of the formula used, which combines the approaches of Stage (1960) and Spurr (1952), is presented as follows:

If the following symbols are used:

$D_{ob}$ present diameter at breast height outside bark,

$d_{ob}$ diameter at breast height outside bark 10 years ago,

$\delta$ diameter at breast height outside bark 10 years hence,

$D_{ib}$ present diameter at breast height inside bark, and

$d_{ib}$ diameter at breast height inside bark 10 years ago,

and assume that the basal area growth in the past 10 years will be equal to the future basal area growth, then:

$$D_{ob}^2 - d_{ob}^2 = {}^2 - D_{ob}^2 \; ;$$

hence
$$\delta^2 = 2D_{ob}^2 - d_{ob}^2 \; ;$$

but
$$d_{ob}^2 = d_{ib}^2 \frac{D_{ob}^2}{D_{ib}^2}$$

(assuming that the $\frac{D_{ob}^2}{D_{ib}^2}$ ratio is constant), then

$$\delta = \sqrt{2D_{ob}^2 - d_{ib}^2 \frac{D_{ob}^2}{D_{ib}^2}} = D_{ob}\sqrt{2 - \left(\frac{d_{ib}}{D_{ib}}\right)^2} \; .$$

Finally the 10-year-diameter growth outside bark is:

$$\delta - D_{ob} = D_{ob}\sqrt{2 - \left(\frac{d_{ib}}{D_{ib}}\right)^2} - 1 \quad .$$

Using this equation, the future 10 years' growth for each sample tree was calculated. An attempt was made to fit a regression equation to the measured data to find future diameter growth for any given diameter, but the equations did not show significant relationship to the present diameters, nor to the crown classes.

Consequently future diameter growth values were plotted against diameters for each species within each type group and freehand curves were fitted to them. Ten-year-growth data taken from these curves are shown by diameter classes in Table 12.

Approximate estimates of deviations and standard error of estimates of diameter growth are shown in Table 11. In this table the average and the maximum deviations of the actual growth from the curved values appear in per cent, and the estimated standard error in inches (i.e., the limits within which two-thirds of the points fell).

TABLE 11

ESTIMATES OF AVERAGE AND MAXIMUM DEVIATIONS AND STANDARD ERRORS OF ESTIMATE OF DIAMETER GROWTH BY SPECIES, AGE AND SITE CLASSES

| | | DEVIATION | | | |
|---|---|---|---|---|---|
| Species | Type | Avg. % | Max. % | S.E.E. In. | No. of trees |
| F | O.G.G. | 40 | 83 | .60 | 40 |
| F | O.G.M. | 45 | 141 | .50 | 53 |
| F | O.G.P. | 50 | 150 | .50 | 22 |
| H | O.G.G. | 55 | 148 | .45 | 26 |
| H | O.G.M. | 60 | 90 | .40 | 19 |
| H | O.G.P. | 35 | 73 | .10 | 5 |
| C | O.G.G. | 45 | 132 | .45 | 29 |
| C | O.G.M. | 50 | 100 | .37 | 75 |
| C | O.G.P. | 55 | 110 | .65 | 22 |
| F | S.G.G. | 36 | 125 | .50 | 44 |
| F | S.G.M. | 36 | 65 | .67 | 23 |
| F | S.G.P. | 31 | 63 | .32 | 18 |
| H | S.G.G. | 20 | 60 | .45 | 20 |
| H | S.G.M. | 25 | 43 | .40 | 24 |
| H | S.G.P. | 40 | 110 | .25 | 16 |
| C | S.G.G. | 23 | 50 | .20 | 8 |
| C | S.G.M. | 40 | 50 | .80 | 22 |
| C | S.G.P. | 20 | 43 | .25 | 12 |

TABLE 12

PREDICTED FUTURE 10-YEAR DIAMETER GROWTH IN INCHES BY DIAMETER, AGE AND SITE CLASSES, AS TAKEN FROM GROWTH CURVES

| TYPE | O.G.G. | | | O.G.M. | | | O.G.P. | | | S.G.G. | | | S.G.M. | | | S.G.P. | | | Y.G.G. | | | Y.G.M. | | | Y.G.P. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SPEC. | F | H | C | F | H | C | F | H | C | F | H | C | F | H | C | F | H | C | F | H | C | F | H | C | F | H | C |
| D.B.H. in. | 10-YEAR DIAMETER GROWTH IN INCHES | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | - | 0.15 | - | - | 0.20 | - | - | 0.37 | 0.38 | - | - | - | - | 0.75 | 0.33 | 0.40 | 0.60 | 0.74 | 4.11 | 3.61 | 5.94 | 2.95 | 3.49 | 5.68 | 3.32 | 2.99 | 4.60 |
| 6 | - | 0.17 | 0.48 | - | 0.32 | 0.34 | - | 0.48 | 0.46 | - | 0.69 | 0.33 | 0.54 | 1.00 | 0.35 | 0.42 | 0.70 | 0.76 | 4.36 | 3.71 | 6.11 | 4.20 | 3.59 | 5.85 | 3.57 | 3.00 | 4.77 |
| 8 | - | 0.22 | 0.62 | - | 0.49 | 0.42 | - | 0.59 | 0.55 | 0.70 | 0.80 | 0.47 | 0.56 | 1.18 | 0.44 | 0.46 | 0.83 | 0.80 | 4.60 | 3.81 | 6.28 | 4.44 | 3.69 | 6.02 | 3.81 | 3.19 | 4.94 |
| 10 | - | 0.30 | 0.80 | - | 0.66 | 0.51 | - | 0.72 | 0.65 | 0.88 | 0.95 | 0.75 | 0.61 | 1.38 | 0.75 | 0.52 | 0.93 | 0.86 | 4.85 | 3.91 | 6.46 | 4.69 | - | 6.20 | 4.06 | - | 5.12 |
| 12 | - | 0.44 | 0.94 | - | 0.82 | 0.62 | - | 0.85 | 0.76 | 1.10 | 1.09 | 1.12 | 0.70 | 1.58 | 1.12 | 0.60 | 1.14 | 0.94 | 5.09 | 4.01 | 6.63 | 4.93 | - | - | 4.30 | | |
| 14 | 0.87 | 0.61 | 1.03 | - | 0.97 | 0.75 | - | 0.97 | 0.85 | 1.40 | 1.24 | 1.48 | 0.85 | 1.76 | 1.48 | 0.70 | 1.31 | 1.04 | 5.34 | 4.10 | 6.80 | 5.18 | | | | | |
| 16 | 0.95 | 0.86 | 1.06 | - | 1.10 | 0.86 | - | 1.04 | 0.91 | 1.75 | 1.34 | 1.85 | 1.15 | 1.90 | 1.75 | 0.81 | 1.42 | 1.18 | 5.58 | 4.20 | 6.98 | | | | | | |
| 18 | 1.04 | 1.00 | 1.07 | - | 1.17 | 0.96 | 0.28 | 1.05 | 0.96 | 2.05 | 1.37 | 2.15 | 1.58 | 1.99 | 1.91 | 0.95 | 1.46 | 1.34 | 5.83 | 4.30 | | | | | | | |
| 20 | 1.10 | 1.02 | 1.06 | 0.20 | 1.21 | 1.02 | 0.32 | 0.98 | 0.98 | 2.25 | 1.35 | 2.38 | 1.85 | 2.02 | 1.98 | 1.12 | 1.41 | 1.42 | 6.08 | | | | | | | | |
| 22 | 1.15 | 0.99 | 1.05 | 0.21 | 1.23 | 1.05 | 0.37 | 0.90 | 0.96 | 2.38 | 1.29 | 2.50 | 1.95 | 2.00 | 1.95 | 1.23 | 1.30 | 1.37 | | | | | | | | | |
| 24 | 1.17 | 0.91 | 1.02 | 0.23 | 1.23 | 1.07 | 0.42 | 0.82 | 0.93 | 2.47 | 1.20 | 2.49 | 1.98 | 1.96 | 1.83 | - | 1.16 | 1.26 | | | | | | | | | |
| 26 | 1.18 | 0.83 | 0.99 | 0.26 | 1.22 | 1.07 | 0.49 | 0.75 | 0.87 | 2.50 | 1.12 | 2.42 | 1.95 | - | 1.67 | - | 1.00 | 1.11 | | | | | | | | | |
| 28 | 1.17 | 0.76 | 0.96 | 0.28 | 1.19 | 1.05 | 0.55 | 0.70 | 0.81 | 2.40 | 1.06 | - | 1.89 | - | 1.52 | - | 0.85 | | | | | | | | | | |
| 30 | 1.16 | 0.70 | 0.94 | 0.31 | 1.15 | 1.02 | 0.62 | 0.66 | 0.75 | 2.44 | 1.00 | - | 1.80 | - | 1.35 | - | 0.71 | | | | | | | | | | |
| 32 | 1.13 | 0.65 | 0.91 | 0.35 | 1.10 | 0.97 | 0.65 | 0.62 | 0.69 | 2.35 | 0.95 | - | 1.74 | - | 1.18 | | | | | | | | | | | | |
| 34 | 1.07 | 0.60 | 0.89 | 0.39 | 1.02 | 0.92 | 0.65 | 0.59 | 0.62 | 2.22 | - | - | 1.68 | | | | | | | | | | | | | | |
| 36 | 1.02 | 0.56 | 0.87 | 0.44 | 0.95 | 0.88 | 0.62 | 0.57 | 0.58 | 2.11 | - | - | 1.62 | | | | | | | | | | | | | | |
| 38 | 0.97 | 0.54 | 0.85 | 0.48 | 0.90 | 0.85 | - | 0.55 | 0.54 | 2.01 | - | - | 1.58 | | | | | | | | | | | | | | |
| 40 | 0.92 | 0.52 | 0.83 | 0.52 | 0.84 | 0.82 | - | 0.54 | 0.50 | 1.92 | - | - | 1.53 | | | | | | | | | | | | | | |
| 42 | 0.88 | 0.50 | 0.82 | 0.56 | 0.80 | 0.80 | - | 0.52 | 0.47 | 1.84 | - | - | 1.50 | | | | | | | | | | | | | | |
| 44 | 0.84 | 0.50 | 0.80 | 0.59 | 0.75 | 0.77 | - | 0.51 | 0.45 | 1.77 | - | - | 1.47 | | | | | | | | | | | | | | |
| 46 | 0.81 | 0.50 | 0.78 | 0.61 | 0.72 | 0.75 | - | 0.50 | 0.42 | - | - | - | 1.44 | | | | | | | | | | | | | | |
| 48 | 0.77 | 0.50 | 0.77 | 0.63 | 0.70 | 0.73 | - | 0.40 | 0.40 | - | - | - | 1.42 | | | | | | | | | | | | | | |
| 50 | 0.75 | 0.50 | 0.75 | 0.64 | - | 0.71 | - | - | 0.39 | - | - | - | 1.39 | | | | | | | | | | | | | | |
| 52 | 0.72 | - | 0.74 | 0.65 | - | 0.70 | - | - | 0.38 | - | - | - | 1.37 | | | | | | | | | | | | | | |
| 54 | 0.69 | - | 0.72 | 0.65 | - | 0.68 | - | - | 0.38 | - | - | - | 1.34 | | | | | | | | | | | | | | |
| 56 | 0.67 | - | 0.71 | 0.65 | - | 0.67 | - | - | - | - | - | - | 1.32 | | | | | | | | | | | | | | |
| 58 | 0.65 | - | 0.70 | 0.65 | - | 0.66 | | | | | | | | | | | | | | | | | | | | | |
| 60 | 0.63 | - | 0.68 | 0.64 | - | 0.65 | | | | | | | | | | | | | | | | | | | | | |
| 62 | 0.61 | - | 0.67 | 0.63 | - | 0.65 | | | | | | | | | | | | | | | | | | | | | |
| 64 | 0.60 | - | 0.65 | 0.62 | - | 0.64 | | | | | | | | | | | | | | | | | | | | | |
| 66 | 0.58 | - | 0.64 | 0.60 | - | 0.64 | | | | | | | | | | | | | | | | | | | | | |
| 68 | 0.57 | - | 0.62 | 0.58 | - | 0.63 | | | | | | | | | | | | | | | | | | | | | |
| 70 | 0.56 | - | 0.61 | 0.56 | - | 0.62 | | | | | | | | | | | | | | | | | | | | | |
| 72 | 0.55 | - | 0.59 | 0.53 | - | 0.62 | | | | | | | | | | | | | | | | | | | | | |
| 74 | 0.54 | - | 0.58 | - | - | 0.61 | | | | | | | | | | | | | | | | | | | | | |
| 76 | 0.53 | - | 0.56 | - | - | 0.60 | | | | | | | | | | | | | | | | | | | | | |
| 78 | - | - | 0.55 | - | - | 0.60 | | | | | | | | | | | | | | | | | | | | | |
| 80 | - | - | 0.54 | - | - | 0.59 | | | | | | | | | | | | | | | | | | | | | |
| 94 | - | - | - | - | - | 0.55 | | | | | | | | | | | | | | | | | | | | | |
| 96 | - | - | - | - | - | 0.54 | | | | | | | | | | | | | | | | | | | | | |

The growth values of the young stands were not based on the calculations presented above, but were evaluated from the equations for them, taken from U.B.C. Forestry Bulletin No. 3, Table 37. The regression equations are:

$$R.G._F = 10.0 + 0.10\ S.I. + 0.78\ D.B.H.,$$

$$R.G._H = 11.3 + 0.08\ S.I. + 0.31\ D.B.H.,$$

$$R.G._C = 13.4 + 0.17\ S.I. + 0.55\ D.B.H.;$$

where $R.G._F$ is radial growth of Douglas fir in millimeters for the past five years,

$S.I.$ is site index in feet at hundred years of age,

$D.B.H.$ is present diameter at breast height in inches,

$R.G._H$ is radial growth of western hemlock in millimeters for the past five years, and

$R.G._C$ is radial growth of western red cedar in millimeters for the past five years.

The equations transformed to give diameter growth in inches for the past ten years appear as follows:

$$D.G._F = 1.57 + 0.0158\ S.I. + 0.1228\ D.B.H.,$$

$$D.G._H = 1.78 + 0.0126\ S.I. + 0.0488\ D.B.H.,$$

$$D.G._C = 2.11 + 0.0268\ S.I. + 0.0866\ D.B.H.;$$

where $D.G.$ is diameter growth at breast height in inches for the past ten years.

## Stand Table Projections

Future volumes by species, age, site and condition classes were essential for later calculations and were calculated using the stand table projection method described in detail by W. H. Meyer (1952).

Local volume tables, constructed for the Research Forest, were used for the estimation of present and future gross cubic foot volumes. In these tables, volumes for different species of various maximum heights ($H_{max}$) are given by one inch diameters.

The following values of $H_{max}$ were used:

| Type | $H_{max}$ |
|---|---|
| S.G.G. | 180 |
| S.G.M. | 160 |
| S.G.P. | 80 |
| S.G.L. | 60 |
| Y.G.G., Y.G.M., Y.G.P. | 240 |

Determinations of the $H_{max}$ classes were based on actual height and diameter measurements. The H/D line is nearly straight for the young age class. No $H_{max}$ was truly suited, but $H_{max}$ 240 was finally chosen. For old growth stands, having only one local volume table, for each species, $H_{max}$ determinations were not necessary. Finally cumulative present and future volumes were calculated for the 3.1, 9.1, 11.1 and 13.1-inch minimum diameter class limits (Tables 6, 13, 14), which are those used as the bases of Fligg's (1960) tables.

TABLE 13

DATA SUMMARY FOR THE RESEARCH FOREST

| D.B.H. Limit in. | Actual Gross Volume | Actual Net Volume | Predicted Gross Volume | 10-yr. Growth Factor | 1 yr. Compound Growth % | Stocked Area acres | Avg. Age yrs. | Average S.I.(F) ft. | Average Species Comp. |
|---|---|---|---|---|---|---|---|---|---|
| | CUBIC FEET | | | | | | | | |
| 3.1 | 50,528,733 | 38,748,893 | - | - | - | | | | |
| 9.1 | 41,947,259 | 35,660,343 | 55,838,019 | 1.331148 | 2.90 | 9,282 | 70 | 124 | HF |
| 11.1 | 38,065,336 | 32,634,095 | 49,069,255 | 1.289079 | 2.57 | | | | |
| 13.1 | 33,891,138 | 29,018,271 | 43,297,373 | 1.277542 | 2.48 | | | | |

## Rotation Age

The determination of the rotation for the University Research Forest has been dealt with by D. Littleton, A. Strother, H. Eidsvik and T. Jeanes (1957), University Research Forest Committee (1959), B. Iverson and R. G. Richards (1959), and R. C. Robertson and J. N. McFarlane (1960). For this reason, in this work, calculations to determine the rotation age were not made, but the recommended rotation age of 80 years for the average site of the Research Forest was accepted.

## Miscellaneous Calculations

In addition to the calculations mentioned above, other information necessary for use in the various formulae and methods were determined.

The calculations of the number of living and dead trees per acre were based on the "blown up" number of trees-per-acre values of the individual trees, previously calculated and sorted by the electronic computer. The sum of the numbers of trees-per-acre values in each diameter class was divided by the number of point samples taken in that age and site class, to supply the final number of trees-per-acre values for the stand table projection.

The ratio of the number of trees per acre that died within the last ten years and the number of living trees per acre in a diameter class gave the desired mortality ratios.

Further valuable information, such as actual and future growing stocks, and simple and compound growth rates, including and excluding ingrowth, were obtained by following the stand table projection method described by W. H. Meyer (1952).

Some of the formulae (W. H. Meyer, Grosenbaugh) necessitated the calculation of the total volumes, volume increments, simple and compound increment rates excluding ingrowth, of stands presently over rotation age. To obtain these data, all samples representing stands over 80 years were selected by age and site classes. After selection, using the newly-obtained number of trees and mortality rates, stand table projections were carried out, which supplied the raw data for the calculations of above-mentioned information.

The transformation of gross cubic foot values to merchantable cubic feet required the use of British Columbia Forest Service reduction factors which were combined to include corrections caused by decay, waste, and breakage, and by intermediate utilization practices. These reduction factors are shown separately for the various species by tree and diameter classes in the Forestry Handbook (1959). Applying these tables to the condition of the U.B.C. Research Forest, it was reasonable to assume that the reduction factors given under tree class one (trees with no visible signs of decay) are suited to second growth and young stands, while the reduction factors under tree class two (trees bearing visible signs of decay) will apply better to the condition of the older growth stands. Regarding merchantable volume factors, it was assumed that intermediate utilization practices will apply to the Research Forest.

When obtaining net volumes, these factors were multiplied by the volumes appearing in the corresponding diameter classes of the stand tables, and summed to the same minimum diameters as the gross volumes. The ratio of the sum of the net cubic foot volumes to the gross volumes at each minimum diameter limit was used as the reduction factor. These factors are shown for old growth and second growth stands in Table 14.

It was necessary to know the average species composition of the age and site classes. The most convenient way to approach this problem was to select the McBee punch cards according to their species composition, and sum their areas. The species composition occupying the largest area of the type was chosen as the representative type of the age and site class and was applied when using the empirical yield tables.

Other calculations, such as average growth and mortality rates, average number of trees, volume ratios, desired growing stock volumes, reduced areas, etc., are described in detail with descriptions of the method or formula in which they were used.

The reliability of the estimated volumes was tested by a comparison which was made between the actual mean yields harvested and recorded during the past, and the estimated yields obtained from the recent survey. The result of this comparison showed a 9.72 per cent underestimate of the recently-estimated

TABLE 14

MISCELLANEOUS DATA REQUIRED FOR THE ALLOWABLE CUT CALCULATIONS

| D.B.H. Limit in. | $V_{Merch}$ cu.ft. | $V_{Total}$ cu.ft. | Ga;k;$V_o$ cu.ft. | Gd;Vn;Gr cu.ft. | $V_{mat}$ cu.ft. | $I_{80}$ cu.ft. | I cu.ft. | MA I cu.ft. | MA II cu.ft. | $I_t$ cu.ft. |
|---|---|---|---|---|---|---|---|---|---|---|
| 3.1 | 12,984,842 | 37,543,891 | 50,528,733 | 24,434,865 | 23,045,882 | 679,305 | - | - | - | - |
| 9.1 | 12,554,464 | 29,392,795 | 41,947,259 | 19,475,956 | 20,331,242 | 592,148 | 599,246 | 12,630 | 6,959 | 13,234,343 |
| 11.1 | 12,404,682 | 25,660,654 | 38,065,336 | 16,323,557 | 18,935,319 | 537,897 | 543,790 | 12,479 | 6,452 | 10,365,840 |
| 13.1 | 12,126,916 | 21,764,222 | 33,891,138 | 13,924,160 | 17,613,700 | 472,826 | 484,159 | 12,200 | 5,823 | 8,714,018 |

| D.B.H. Limit in. | $G_o$ | $G_1$ | $Y_{110}$ cu.ft. | $Y_{123}$ cu.ft. | $(1+g_t)^t$; $(1.0\,p)^t$ | $(1+g_M)^t$ | $g_M$ | $g_t$;0.0p | $V_m$;K cu.ft. | Yr | Merch.Red. Fact.O.G. | Merch.Red. Fact.S.G. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.1 | - | - | 7,935 | 9,022 | - | - | - | - | 47,267,000 | 6119 | 0.57852 | 0.61106 |
| 9.1 | 0.01010 | 0.033115 | 7,398 | 8,685 | 1.33115 | 1.100997 | 0.0097 | 0.0290 | 39,138,346 | 5250 | 0.58122 | 0.76891 |
| 11.1 | 0.00934 | 0.028908 | 6,890 | 8,103 | 1.28908 | 1.093447 | 0.0090 | 0.0257 | 35,347,614 | 4774 | 0.58064 | 0.77965 |
| 13.1 | 0.00875 | 0.027754 | 6,301 | 7,487 | 1.27754 | 1.0875149 | 0.0084 | 0.0248 | 31,395,266 | 4290 | 0.57947 | 0.78125 |

NOTE: COLUMN HEADINGS ARE IDENTICAL TO THOSE USED IN FORMULAE AND ALL TERMS ARE DEFINED IN EXAMPLES GIVEN LATER.

volumes, when the volume per acre at a minimum diameter of 9.1 inches was compared to the average actual cutting volume per acre.

Naturally a discrepancy of this scale can be due to the difference in the actual and the estimated losses caused by waste, breakage and decay, or in minor differences in site index or stocking. It can be realistically assumed that in the case of the Research Forest the losses through breakage and waste were smaller than those indicated by the B.C. Forest Service for an average logging operation.

TABLE 15

A COMPARISON OF ACTUAL AND ESTIMATED OLD GROWTH YIELDS

| | Estimated | | | | Actual | Difference | |
|---|---|---|---|---|---|---|---|
| Type | D.B.H. limit in. | Vol./ac. Gross cu.ft. | Red. fact. | Vol./ac. Net cu.ft. | Vol./ac. Net cu.ft. | Net cu.ft. | per cent |
| O.G.M. | 9.1 | 13,307 | 0.58122 | 7,734 | 8,486 | 752 | 9.72 |

The actual net cubic foot volume per acre is an average, calculated from the recorded board feet harvest volumes of the timber sales 3, 12, 13, 14, 16A, 16B, 17, 19, 22, 23, 26, using a conversion factor of 0.1666. These sales were mostly in old growth and covered about 504 acres.

In second growth stands data published by Smith and Ker (1959) gave the bases for volume comparison. In this publication average volumes of 87 plots covering a total of 28 acres were given, together with the average age, site index and other data. The comparison showed that the recently estimated weighted average volumes in the second growth types were 9.6 per cent higher than the average volumes shown by Smith and Ker. However, it must be noticed that the average age of the plots used by Smith and Ker (66 years) was considerably lower than the one estimated in 1961 (80 years). On the other hand, the average site index given by Smith and Ker was higher by 11 feet than the recent estimate.

TABLE 16

A COMPARISON OF SECOND GROWTH VOLUMES AS ESTIMATED IN 1959 (SMITH AND KER, 1959) AND IN 1961

| Type | D.B.H. Limit in. | Volume per acre (1959) cu.ft. | Volume per acre (1961) cu.ft. | Difference Vol./ac. cu.ft. | Difference Per cent |
|---|---|---|---|---|---|
| S.G. | 3.1 | 8,623 | 9,407 | 781 | 9.06 |

Total volumes of Douglas fir, hemlock, and cedar on the Forest might be increased by 16, 15, 14 and 12 per cent corresponding to 3.1, 9.1, 11.1 and 13.1 inches minimum diameter limits, if areas occupied by deciduous species are added. Not more than a further 5 per cent would be in coniferous species other than Douglas fir, hemlock, and cedar.

## ALLOWABLE CUT CALCULATIONS

Under this title, for each method or formula a detailed evaluation will be presented and will apply to a minimum diameter limit of 11.1 inches. The results for the other minimum diameter classes together with the 11.1 inch class appear in Table 20.

### Area Regulation

For this method, a series of calculations had to be made. It was assumed that the present ratio of the actual volume to the empirical volume will remain the same in the S.G.G., S.G.M. and S.G.P. stands until cutting.

The method used is described in detail below.

Before calculations could begin, the types had to be listed in the order of preference for cutting.

The logical order was to cut the overmature stands, cutting the best sites first, ensuring that these good sites will return first to production from the present stagnant or decadent stage. In second growth stand, however, the reason for cutting the better sites is different. Here the poorer sites need a longer rotation to produce the same size of wood as a better site could in a shorter rotation period.

Concerning the younger age classes, it was assumed for the purpose of these calculations that within the next ten years the deciduous stands will be cut, and replaced by establishing a FH type stand, which has a -5 year average present age.

Having decided the order of cutting, the corresponding average ages and actual areas in acres had to be shown.

The next step was to reduce the actual areas to standard productivity. For this purpose a FH medium type was chosen as standard. The required reduction factor (RF) then becomes:

$$RF = \frac{\text{Volume of actual type at approximate rotation age}}{\text{Volume of HF medium type at approximate rotation age}} .$$

For old growth stands the present volume was substituted into the numerator, while in the denominator the empirical volume of HF medium type at 375 years was inserted.

For second growth stands, with the exception of second growth low site class, the empirical yield for cutting age was multiplied by the actual volume ratio (VR),

$$VR = \frac{\text{present volume}}{\text{empirical volume}} ,$$

to obtain correct future volumes. The volume obtained this way then had to be divided by the volume of the HF medium stand to give a realistic reduction factor.

Knowing the reduced acre values of each condition class, the determination of the allowable cutting area was now easily calculated by summing up the reduced areas and dividing the sum by the rotation age (131.325 reduced acres).

The duration of the cut within a type can be computed if the area of the type is divided by the yearly cutting area. If this duration of cut is added to the present age of the next type, the age when cutting begins is obtained.

The average cutting age for the second type now is given if half of its cutting duration time is added to the age when cutting begins. At the average cutting ages, the corresponding empirical volumes are read from the empirical yield table and multiplied by the present area of the type. This value will be the final yield when the type will be cut. (Obviously the empirical volumes for S.G.G., S.G.M., S.G.P. are corrected by the present volume ratio.)

If the sum of the final yields at cutting age is divided by the rotation the average yearly cut is readily obtained.

Detailed calculation of the method is shown in Table 17.

The calculation clearly indicates the large yearly volume differences, if the given cutting sequence were followed. By this method the old growth types would be removed very quickly (8 years) during which period large yearly harvest volumes would appear (approximately 1,560,000 gross cu. ft. per year).

After this period the yearly cutting volume would drop sharply, to the vicinity of 70-80,000 cu. ft. per year, with occasional fluctuations, averaging for the whole rotation period a figure of 847,000 cu. ft. per year.

The above calculation presupposes that the deciduous types will also be cut and regenerated within the next 10 years. (The volumes presently standing on these types were not taken into consideration.)

TABLE 17

EXAMPLE OF AREA REGULATION

| Type | Spec. Comp. | Site | Act. Avg. Age yrs. | Act. Area ac. | Red. Fact. | Red. Area ac. | Avg. Age When Cut yrs. | Yield per ac. When Cut cu.ft. | Tot.Exp. Yield cu.ft. | Yrs. to Cut Yrs. Per. | Yrs. to Cut Yrs. Cum. | Yearly Cut cu.ft. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O.G.G. | HF | G | M | 159 | 1.118 | 178 | M | 13,493 | 2,145,387 | 1.4 | 1.4 | 1,532,419 |
| O.G.M. | CH | M | M | 671 | 1.093 | 734 | M | 13,193 | 8,852,503 | 5.6 | 7.0 | 1,580,804 |
| O.G.P. | CH | P | M | 164 | 0.711 | 117 | M | 8,578 | 1,406,792 | 0.9 | 7.9 | 1,563,102 |
| S.G.G. | FH | G | 70 | 805 | 1.751 | 1410 | 85 | 10,031 | 8,074,955 | 10.7 | 18.6 | 754,669 |
| S.G.M. | FH | M | 80 | 1885 | 1.784 | 3363 | 113 | 9,850 | 18,567,250 | 25.6 | 44.2 | 725,283 |
| S.G.P. | HF | P | 90 | 968 | 0.391 | 378 | 137 | 3,467 | 3,356,056 | 2.9 | 47.1 | 1,157,261 |
| S.G.L. | FH | L | 90 | 43 | 0.212 | 9 | 139 | 1,787 | 76,841 | 0.1 | 47.2 | 768,410 |
| Y.G.G. | HC | M | 30 | 2170 | 1.000 | 2170 | 87 | 5,783 | 12,549,110 | 16.5 | 63.7 | 760,552 |
| Y.G.M. | HC | M | 25 | 1171 | 1.000 | 1171 | 95 | 6,348 | 7,433,508 | 8.9 | 72.6 | 835,226 |
| Y.G.P. | CH | P | 20 | 335 | 0.481 | 161 | 95 | 3,127 | 1,047,545 | 1.2 | 73.8 | 872,954 |
| PL. | FH | M | 5 | 558 | 0.904 | 505 | 82 | 4,937 | 2,754,846 | 3.8 | 77.6 | 724,959 |
| HW. | FH | M | -5 | 353 | 0.878 | 310 | 74 | 4,300 | 1,517,900 | 2.4 | 80.0 | 632,458 |
| TOTAL | | | | | | 10,506 | | | 67,782,693 | | | |

TOTAL REDUCED AREA: 10,506 acres.

YEARLY CUTTING AREA = 10,506 : 80 = 131.325 reduced acres.

AVERAGE YEARLY VOLUME CUT = 67,782,693 : 80 = 847,284 cu. ft.

(continued)

TABLE 17

EXAMPLE OF AREA REGULATION (Continued)

Calculation of the Reduction Factors

| Type | Spec. Comp. | Approx. Cutting Age(yrs) | Emp. Yield at Cut.age. cu.ft. | Volume Ratio | Yield at Cutting Age cu.ft. | Yield of HF med. at Cutting Age cu.ft. | Red. Fact. |
|---|---|---|---|---|---|---|---|
| O.G.G. | HF | M | | | 13,493 | 12,067 | 1.1181 |
| O.G.M. | CH | M | | | 13,193 | 12,067 | 1.0933 |
| O.G.P. | CH | M | | | 8,578 | 12,067 | 0.7108 |
| S.G.G. | FH | 80 | 6,076 | 1.5213 | 9,243 | 5,278 | 1.7512 |
| S.G.M. | FH | 110 | 7,084 | 1.8446 | 13,067 | 7,324 | 1.7841 |
| S.G.P. | HF | 130 | 5,124 | 0.6492 | 3,226 | 8,510 | 0.3908 |
| S.G.L. | FH | 140 | 1,914 | | 1,914 | 9,021 | 0.2121 |
| Y.G.G. | HC | 80 | 5,278 | | 5,278 | 5,278 | 1.0000 |
| Y.G.M. | HC | 90 | 5,999 | | 5,999 | 5,999 | 1.0000 |
| Y.G.P. | CH | 90 | 2,888 | | 2,888 | 5,999 | 0.4814 |
| PL. | FH | 80 | 4,774 | | 4,774 | 5,278 | 0.9045 |
| HW. | FH | 70 | 3,982 | | 3,982 | 4,534 | 0.8782 |

Although, this way within an 80-year period a complete regularity could be achieved, the classical area method is not flexible enough to take into consideration the changing market conditions, availability of manpower, demand for specific log sizes, etc., and therefore the strict application of the method usually is neither practical nor economical.

At the present time the area method of regulation is being applied rather flexibly on the University Research Forest. Actual area harvested is to be within 30 per cent of the allowable for any one year, within 10 per cent for a decade, and should balance in a 20-year period. There is no doubt that it is both simple and convenient in planning and in application. Costs of operational cruising can be reduced and records can be based on scaled volumes and actual areas logged. The large volumes and values of the old growth stands currently being logged can be used to finance the high costs of road building associated with a staggered setting pattern of logging. In addition, logging of the large volumes in dead cedar trees killed by the fire of 1868, and the snags, chunks and logs left after the original logging by the Abernethy and Lougheed company are actually considered as salvage operations. These have been scheduled to be completed by approximately 1970 and have not been entered directly into either area or volume calculations presented here. It is to be hoped that volumes and values secured from these activities will be compensated by thinnings by 1970. Areas thinned can also be excluded from area calculations provided there is reasonable assurance that values of the final crop will not be diminished by thinning.

## Volume Control Formulae

### Austrian formula

The only assumption that had to be made for this formula was concerned with the future or desired growing stock at the end of the rotation. It was assumed that future plantations, will also use Douglas fir seedlings. These plantations likely will be filled in with natural regeneration of hemlock and cedar, to form a FH-type stand. Using the average Douglas fir site index value (124) for the Research Forest, the empirical growing stock for a FH medium type was calculated and inserted into the equation as the desired growing stock.

$$AC = I + \frac{Ga - Gr}{R} = 543{,}790 + \frac{38{,}065{,}336 - 16{,}323{,}557}{80} =$$

$$815{,}562 \text{ gross cu. ft./year.}$$

The increment in this case is the mean annual increment of the total stand, obtained as total actual volume divided by the average weighted age. Comparing this result to the average volume value indicated by the area regulation it appears that the two values are very similar.

Hanzlik's formula

Data taken from Table 14 applicable to this formula are as follows:

$$I_{80} = 556{,}615 \text{ cu. ft.}$$

$$V_{mat} = 18{,}935{,}319 \text{ cu. ft.}$$

$I_{80}$ is the mean annual increment taken from the empirical yield table at R = 80 years for each type and multiplied by the area of the type. The values read for S.G.G., S.G.M., and S.G.P. were corrected with the present volume ratio. Because these stands are very close to the rotation age, it can be assumed that they will retain the existing ratio to the empirical values for this short period.

$V_{mat}$ is the volume of stands over 80 years of age.

The rotation used in this formula is 80 years. The allowable cut is:

$$A.C. = I_{80} + \frac{V_{mat}}{R} = 537{,}897\ \frac{18{,}935{,}319}{80} = 774{,}588 \text{ gross cu. ft./year.}$$

Although this formula is widely used on the West Coast of North America in the Douglas fir type, it has the weakness that the mean annual increment of the presently young stands cannot be accurately predicted for a long period of time. Also, through improvement in silviculture and management, the mean annual increment may be far greater than that indicated in empirical yield tables. Therefore, for rough estimation it gives a satisfactory allowable cut estimate in virgin stands, but in managed stands the answer is usually conservative.

Kemp's formula

The result of this formula can be greatly influenced by the decision of the forest manager concerning the areas which he inserts into the formula. The decision usually cannot be made simply by considering the present age class distribution because the actual stands may be of different sites, and produce greater or lesser volumes than were presupposed by the creation of the formula. An approximate estimation based on size classes can substitute for the definition based on the age classes (Kemp I, II) or a standard age and site class must be chosen and the ages reduced accordingly. That is, the volume of each actual age and site class will be compared to the basic age and site class for which the corresponding age will be read from the empirical yield table.

This way a realistic age class distribution for all the existing types and sites will be obtained, and the decision of classes can be easily made (Kemp III).

In the first trial (Kemp I) the following types were included in the classes:

$A$ (area of saw timber stands) = O.G.G., O.G.M., O.G.P.,

$A_1$ (area of pole timber stands) = S.G.G., S.G.M., S.G.P., S.G.L., Y.G.G.,

$A_2$ (area of seedlings, saplings) = Y.G.M., PL., HW.,

$A_3$ (non-stocked area) = Y.G.P.

$A = 994$ ac. $A_1 = 5,871$ ac. $A_2 = 2,082$ ac. $A_3 = 335$ ac.

Using the average volume of O.G.G., O.G.M., O.G.P., stands MA I = 12,479 cu. ft. per acre, the allowable cut:

$$\text{A.C.} = \frac{7(994) + 5(5,871) + 3(2,082) + 335}{4(80)} (12,479) =$$

1,672,812 gross cu. ft./year.

This indicated cut is high compared to the other formulae. The reason for this high volume is that the per-acre yield is very large in the old growth stands. However, if we compute the average volume of all stands at rotation age the allowable cut becomes more reasonable (Kemp II).

Using the same A values, and the average yield when stands are cut (MA II), taken from area regulation, we obtain:

$$\text{A.C.} = \frac{7(994) + 5(5,871) + 3(2,082) + 335}{4(80)} (6,452) =$$

864,850 gross cu. ft./year.

The most logical approach for these stands may be the third one, suggested previously.

The basic type to which all ages were reduced was arbitrarily decided (HF medium). This way the selection into four age classes with the reduced ages was more realistic than the previous size selections. The new grouping, done by 20-year age classes, is shown below:

A ( 60+ years) O.G.G., O.G.M., O.G.P., S.G.G., S.G.M. = 2,518 reduced acres,

$A_1$ (40-60 years) S.G.P. = 968 reduced acres,

$A_2$ (20-40 years) = 0 reduced acres,

$A_3$ ( 0-20 years) S.G.L., Y.G.G., Y.G.M., Y.G.P., PL., HW. = 4,630 reduced acres.

Here MA I was taken as the average cutting volume of old growth stands. Introducing these values into the formula:

$$A.C. = \frac{7(2,518) + 5(968) + 3(0) + 4,630}{4(80)} (12,479) =$$

1,056,659 gross cu. ft./year.

This cut is higher than those obtained by Hanzlik's or the Austrian formula, but may be justified for the first 10 or 20 years to eliminate the large quantities of mature volumes.

Barnes' method

When the average age of the hardwood stands was taken as -5 years, the average weighted age of the present stand calculated from all the individual types gave the figure of 70 years. Using a rotation of 80 years, the average age should have been

40 years, if the stand were normal. The discrepancy is therefore 70 - 40 = 30 years, with which the average cutting age of the present stand will have to be increased, i.e., the average cutting age will become 80 + 30 = 110 years. An estimation of the yield at this age will give the allowable cut for the present stands.

Yields at age 110 years were read from the empirical yield tables for each age and site class, and weighted by the area of the class.

The final value calculated was the average weighted yield of all classes at 110 years, which had to be multiplied by the yearly reduced cutting area ($A_R$), taken from the area regulation method, to obtain a correct answer.

To clarify:- If 1/80th of the total actual area was taken, the average yearly cutting area would indicate a mixed, indefinite type, and site class. The reduced areas show an area-equivalent of the present types and sites, as if they all were HF type, and medium site quality. In other words, the areas were reduced to standard productivity.

The allowable cut is:

$$A.C. = (A_R)\ (Y_{110}) = (131.325)\ (6890) = 904,775 \text{ gross cu.ft./year.}$$

An improvement of the method would be to use reduced ages for the determination of the average present age, instead of the actual ages. The reduced ages are obtained in a similar way to that described for the Kemp III formula. These must be weighted by the appropriate areas to obtain the correct average reduced age for the whole area. By evaluating the new average age we obtain 83 years, which is 13 years more than the average age of the actual types. Hence the new estimate of the average cutting age will increase also, giving the value of 132 years. At this age the yield of a HF medium site stand ($Y_{132}$) is 8,612 cu. ft. above the 11.1 inch minimum diameter, and the new allowable cut becomes:

A.C. = (131.325) (8,612) = 1,130,971 gross cu. ft./year.

This allowable cut corresponds fairly well with the one obtained with the Kemp III formula.

Black Hills formula

For this formula, the following assumptions and definitions had to be made:

1. Since in the University Research Forest there is no marking practice at present, it had to be assumed that all volumes will be taken from the presently overmature stands.

2. $V_M$ was interpreted as the volume in overmature stands (O.G.G., O.G.M., O.G.P.) and it was assumed that half of their volume would be cut within the coming ten years ($C_M$ = 0.50).

3. $V_t$ became the volume of all other stands above minimum diameter limits.

4. It was assumed that 1/8th of the volume of $V_t$ and half of its increment during the cutting cycle would also be cut.

5. The period of the cutting cycle y was taken as 10 years.

Inserting the assumed and actual values into the formula, the allowable cut became:

$$A.C. = \frac{12,404,682(0.50) + (25,660,654 + \frac{10,365,840}{2})\,0.125}{10} =$$

1,005,804 gross cu. ft./year,

which, in comparison with the other allowable cut estimates indicates a reasonable level of cut for the coming decade.

Hundeshagen's formula

On the basis of the average site and the assumed future species composition, the desired growing stock was calculated from the empirical yield table (Fligg, 1960), for FH medium site.

$$G_r = 16,323,557 \text{ cu. ft.},$$

whereas the actual growing stock is

$$G_a = 38,065,336 \text{ cu. ft.}$$

The ratio of these figures:

$$\frac{G_a}{G_r} = \frac{38,065,336}{16,323,557} = 2.33192.$$

The empirical yield at 80 years of a FH medium type stand is:

$$Y_r = 4,774 \text{ cu. ft./acre.}$$

The empirical yield for one year, therefore, is $\frac{4,774}{80} = 59.675$ cu.ft.

Hence the actual yield per acre:

$$Y_a = (2.33192)(59.675) = 139.1573 \text{ cu. ft./year.}$$

The total yield for the Forest, therefore, is:

$$Y_a \text{ (total)} = 9,282(139.1573) = 1,291,658 \text{ gross cu. ft./year.}$$

The reliability of this figure - because of the inherent faults of its assumptions - is not very high. Though, it might be used as an auxiliary or control for the other allowable cut estimates.

H. A. Meyer's method

When calculating the allowable cut with this method, the process outlined below was followed:

1. The weighted average number of trees per acre including all species was calculated for each diameter class. That is, the number of trees per acre of each age and site class weighted by the actual areas they occupy.

2. The average weighted volume per acre including all species was computed.

3. The average diameter growth per year including all species (average of the data in Table 3) was calculated.

4. A regression equation was fitted to the logarithmically-transformed data of the average number of trees per acre calculated for the whole Forest:

$$\log N = 1.7985 - 0.05972 \text{ D.B.H.},$$

where N = number of trees per acre in diameter class,

D.B.H.= diameter at breast height in inches.

The regression equation was highly significant at the 1 per cent level.

5. Through the substitution of the appropriate values into the equation, given by Sammi (1960), the de Liocourt's quotient

was obtained (q = 1.3293).

This value was under the q shown for well-managed Swiss forests, and needed no reduction.

6. Knowing q and the average growth rates by diameter classes, the per cent volume increase could be read from Table 32 (Meyer, Recknagel and Stevenson, 1952).

7. The volume per cent read from the table multiplied by the volume per acre value of a diameter class shows the yearly volume increase of the class.

8. Summing up the volume increases of each diameter class up to the desired minimum diameter limit, the yearly gross volume increase of the stand is obtained.

9. Average yearly mortality in number of trees per acre was calculated by diameter classes.

10. The average volume of a tree in a diameter class was obtained as $\frac{\text{average volume per acre}}{\text{number of living trees per acre}}$.

11. The multiplication of the average volume per tree by the number of dead trees in a diameter class gave the mortality losses within that class.

12. The cumulative mortality losses subtracted from the cumulative annual volume increase figures equalled the cumulative net volume increase of the Forest in cu. ft.

13. A maximum diameter limit of 30 inches was set, beyond which all trees were to be cut within a predetermined period.

14. The elimination of trees larger in diameter than 30

inches was set to 80 years, and also for comparative purposes to 20 years.

15. During the elimination period, it was assumed that all the net volume increment below 30 inches in diameter, plus 1/8th (or respectively 1/20th) of the volume of trees 30 inches and larger and half of the increment of this latter class, would be cut.

Since the necessary information for this method was calculated in merchantable cubic feet, the allowable cut obtained for the two different assumptions is also given in the same units:

$$A.C._{80} = 531{,}585 \text{ net cu. ft./year,}$$

$$A.C._{20} = 745{,}858 \text{ net cu. ft./year,}$$

where $A.C._{80}$ = the yearly allowable cut, when the 80-year conversion period is used, and

$A.C._{20}$ = the yearly allowable cut, when the 20-year conversion period is used.

Assuming that the cut will be taken in mature stands, the gross volumes will read:

$$A.C._{80} = 914{,}326 \text{ gross cu. ft./year,}$$

$$A.C._{20} = 1{,}282{,}876 \text{ gross cu. ft./year.}$$

The possible reason for the lower estimate in the 80-year conversion period is that the q value might have been underestimated as a result of the present understocked condition of the young growth stands, or because of the use of unweighted average growth rates.

As a final conclusion concerning the use of the method, it might be stated that, considering the long and tiresome calculations, which are open to the risk of human error, the effort spent in obtaining an estimation of the allowable cut with this method is not justified. Nevertheless, there is some value in the stand table and the growth and mortality data for their own sake as a guide to management.

Von Mantel's formula

In contrast with H. A. Meyer's somewhat complicated method, Von Mantel's formula, often called one of "glorious simplicity", with the substitution of only two figures, gives the following result:

$$\text{A.C.} = \frac{2(38{,}065{,}336)}{80} = 951{,}633 \text{ gross cu. ft./year,}$$

where the figure 38,065,336 means the actual growing stock in cubic feet, and 80 is the rotation in years.

Considering the volume distribution of the Forest (Figure 2) the allowable cut indicated by this formula should be fairly reasonable. However, because of the fast growth rate of the young stands, and the large areas of overmature timber in need of removal, the result might be judged somewhat conservative for the coming decade.

Grosenbaugh's simple interest formula

The following actual and estimated values were used in this formula:

$m$ = 10 years,

$n$ = 80 years,

$V_o$ = 38,065,336 cu. ft.,

$V_n$ = 16,323,557 cu. ft.

$V_n$, the future growing stock figure, was assumed for 80 years hence, and was read from the empirical yield table for FH stands at medium site.

$G_o$ = 0.0093,

$G_1$ = 0.0289;

$G_o$ was calculated from the increment values of stands presently older than 80 years, whereas $G_1$ shows the growth rate of the entire growing stock predicted for the next 10 years.

$G_2$ = 0.05.

This figure is an estimated value of the growth rate expected over the 80-year period, and is estimated to come from the results of improved management, silviculture (thinning, salvage, removal of slow-growing old growth stands), planting, etc.

By substituting these figures into Grosenbaugh's formula, the estimated allowable cut for the next decade is:

$$\text{A.C.} = 38{,}065{,}336 \left[\frac{1+80(0.05)-\frac{16{,}323{,}557}{38{,}065{,}336}}{80(0.05)}\right]\left[10(0.0289)\right]\left[\frac{\frac{10}{1+2(0.00934)}}{1+10(0.00934)}\right] =$$

12,037,782 cu. ft./10 years, or 1,203,778 cu. ft./year.

After the first ten-year period this high indicated cut would likely be reduced because most of the slow-growing stands of the Research Forest will be removed.

W. H. Meyer's amortization formula

Information needed for this formula, as applied to the Research Forest, is listed and explained below:

$V_o$ = 38,065,336 cu. ft.,

$V_m$ = 35,347,614 cu. ft.

Assuming that 80 years hence the Research Forest will have the growing stock of a FH medium site (16,323,557 cu. ft.), and in the next decade 1/8th of the volume difference of the present and desired growing stock will be cut, then the future volume 10 years hence can be calculated as: The present growing stock minus 1/8th of the volume difference. I.e.

$$V_o = 38{,}065{,}336 - \frac{38{,}065{,}336 - 16{,}323{,}557}{8} = 35{,}347{,}614 \text{ cu. ft.,}$$

where $n$ = 10 years,

$(1+g_t)^t$ = 1.28908,

$(1+g_M)^t$ = 1.0934,

$g_M$ = 0.009,

$$\text{A.C.} = 0.009\ \frac{38{,}065{,}336(1.8908) - 35{,}347{,}614}{1.0934 - 1} = 1{,}321{,}528 \text{ gross cu. ft./year.}$$

Sven Petrini's interest formulae

Compound interest (I)

This formula is identical to the one which was originally devised by W. H. Meyer in 1943, and gives a slightly lower estimate of the allowable cut than the amortization formula above.

Using the corresponding values of the Research Forest, the following values can be substituted into the formula:

$$(1.0p)^t = 1.28908,$$

$$k = 38{,}065{,}336 \text{ cu. ft.},$$

$$K = 35{,}347{,}614 \text{ cu. ft. and}$$

$$0.0p = 0.0257.$$

Here $(1.0p)^t$, k, and K are similar to W. H. Meyer's $(1+g_t)^t$, $V_o$ and $V_m$ values respectively. The only exception is, in this formula, the compound interest rate of the whole stand (0.0p) is used in the places of Meyer's $g_M$ value, giving an allowable cut of:

$$A.C. = 0.0257 \, \frac{38{,}065{,}336(1.28908)-35{,}347{,}614}{1.28908 - 1} = 1{,}219{,}892 \text{ cu. ft./year.}$$

Since the largest ingrowth occurs in the young stands, which at present are understocked and need to be increased in stocking, the allowable figure given by this formula may better fit the actual situation than the improved W. H. Meyer's amortization formula.

Simple interest formula (II)

Using the values of the Research Forest the following figures were substituted into the formula:

$$t = 10 \text{ years},$$

$$p = 2.8908 \text{ per cent},$$

$$k = 38{,}065{,}336 \text{ cu. ft.},$$

$$K = 35{,}347{,}614 \text{ cu. ft., and}$$

$$(1+\frac{tp}{100}) = 1.28908,$$

hence, the allowable cut is:

$$A.C. = \frac{38,065,336\ (1.28908) - 35,347,614}{10\left[1 + \frac{10\ (2.8908)}{200 + 10\ (2.8908)}\right]} = 1,218,306 \text{ cu. ft./year.}$$

This figure, from the management point of view, is identical to the one obtained by the compound interest formula, and the final comments made previously apply to the simple interest formula as well.

## Area and Volume Control Methods

### Area-volume computation

This is a method adapted for the use of empirical yield tables, from the Reports of the West Coast Forest Procedures Committee (1950).

The method starts out stating the types, present ages, and actual and reduced areas, as in the area regulation, and must be accompanied by an approximate yearly cut figure obtained from one of the allowable cut formulae.

Then a preliminary estimate is obtained of the cutting age and total yield for each age and site class, in a similar way to that described in the area method. This estimate of the total yield is divided by the preliminary allowable cut figure, to see how long this volume will last, if this preliminary figure were cut each year. When half of the duration period is added to the age when cutting starts, the sum will give the final cutting age of the age and site class in question. At this age the yield is read from the empirical yield table (for S.G.G., S.G.M., S.G.P., yields are corrected by the present volume ratio) and multiplied by the actual acres of the type. Finally this volume, divided by the preliminary allowable cut, will give the final duration of the cut within that class, which then is added to the cumulative column of the table.

Turning to the next age and site class, the initial cutting age is obtained, when the last figure of the cumulative age column is added to the present age of this class. All further calculations from here on proceed as described above.

If the final figure in the cumulative age column is within the range of the desired limit $R(1 \pm 0.05)$, then the preliminary allowable cut figure is acceptable. If not, a new allowable cut estimate must be set, making the new estimate higher, when the final cumulative age was high, or lower, if it was low, and the process repeated accordingly.

For the Research Forest the first estimate of 870,000 cu. ft. of the allowable cut proved to be low. With a second trial figure of 970,000 cu. ft., the final figure of the cumulative column was within the limit, but lower than the rotation age (77 years). Taking this into consideration, the 970,000 cu. ft. was lowered to 960,000 cu. ft. and accepted as the final estimate.

The method is presented in detail in Table 18.

TABLE 18

EXAMPLE OF AREA-VOLUME COMPUTATION,

USING PRELIMINARY ALLOWABLE CUT ESTIMATE OF 970,000 cu. ft.

| Type | Spec. Comp. | Site Class | Avg. Actual Age yrs. | Actual Area ac. | R. F. | Red. Acres | Cut Begins at Age yrs. | Avg. Cut. Age yrs. | Yield per acre When Cut cu.ft. | Actual Approx. Yield When Cut M.cu.ft. | Avg. Cut. Age yrs. | Yield per Acre When Cut cu.ft. | Actual Yield When Cut cu.ft. | Years to Cut Per. | Years to Cut Cum. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O.G.G. | HF | G | M | 159 | 1.118 | 178 | M | M | 13,493 | 2,140 | M | 13,493 | 2,145,387 | 2.2 | 2.2 |
| O.G.M. | CH | M | M | 671 | 1.093 | 734 | M | M | 13,193 | 8,850 | M | 13,193 | 8,852,503 | 7.1 | 11.3 |
| O.G.P. | CH | P | M | 164 | 0.711 | 117 | M | M | 8,578 | 1,380 | M | 8,578 | 1,388,096 | 1.4 | 12.7 |
| S.G.G. | FH | G | 70 | 805 | 1.751 | 1,410 | 83 | 88 | 10,504 | 8,470 | 87 | 10,346 | 8,328,530 | 8.6 | 21.3 |
| S.G.M. | FH | M | 80 | 1,885 | 1.784 | 3,363 | 101 | 114 | 13,550 | 25,500 | 114 | 13,609 | 25,652,965 | 26.5 | 47.8 |
| S.G.P. | HF | P | 90 | 968 | 0.391 | 378 | 138 | 139 | 3,510 | 3,350 | 140 | 3,512 | 3,339,616 | 3.4 | 51.2 |
| S.G.L. | FH | L | 90 | 43 | 0.212 | 9 | 141 | 141 | 1,925 | 80 | 141 | 1,925 | 82,775 | 0.1 | 51.3 |
| Y.G.G. | HC | M | 30 | 2,170 | 1.000 | 2,170 | 81 | 90 | 5,963 | 12,900 | 88 | 5,847 | 12,687,990 | 13.1 | 64.4 |
| Y.G.M. | HC | M | 25 | 1,171 | 1.000 | 1,171 | 89 | 94 | 6,278 | 7,340 | 93 | 6,222 | 7,285,962 | 7.5 | 71.9 |
| Y.G.P. | CH | P | 20 | 335 | 0.481 | 161 | 82 | 83 | 2,541 | 850 | 82 | 2,519 | 843,865 | 0.9 | 72.8 |
| PL. | FH | M | 5 | 558 | 0.904 | 505 | 78 | 80 | 4,750 | 2,650 | 79 | 4,702 | 2,623,716 | 2.7 | 75.5 |
| HW. | FH | M | -5 | 353 | 0.878 | 310 | 71 | 72 | 4,117 | 1,450 | 71 | 4,077 | 1,439,181 | 1.5 | 77.0 |
| | | | | | | 10,506 | | | | | | | | | |

YEARLY CUTTING AREA: 10,506 : 80 = 131.325 reduced acres

Area-volume allotment

As a necessary step to begin the calculations, the cutting cycle had to be chosen, for which the allowable cut will be calculated. This was set at ten years, which is comparable to the period for some of the other calculations.

In this method, the same types, actual ages, actual and reduced areas were used as in the area regulation, or as in the area-volume computation. The reduced cutting area during the cutting cycle became ten times the size of the one year cutting area, giving a figure of 1,313 reduced acres. The reduced areas of the condition classes, listed in their order of cutting sequence, were added until the sum was equal to 1,313 acres.

The next step was to set the average cutting age of the age and site classes, at which the yields had to be found in the empirical yield table. This age was assumed to be equal to the initial age plus half of the cutting cycle (5 years) for the first period, and the initial age and one and one-half cutting cycles (15 years), for the second period. At this age, the yields read from the empirical yield table represented the final yields of the age and site class. (At this point it must be noted that similarly to the area regulation and to the area-volume computation, for the old growth stands, the present volumes were assumed as cutting volumes. For the second growth stands the future empirical yields were multiplied by the present volume ratios, assuming that this ratio will remain constant during the next five- or fifteen-year period.) The sum of the volume per acre figures multiplied by the actual areas of the age and site classes gave the total gross cubic foot volumes cut during the cutting cycles. As a result of the large harvest volumes in the old growth stands, in the first cutting cycle nearly twice as much volume appeared as in the second, which was composed of second growth stands. To moderate the large volume differences occurring between the two cutting cycles, the total yields obtained for the two cycles were averaged and the corresponding reduced acres recalculated. Obviously, the reduced acre values became lower in the first cycle and larger in the second, as a consequence of the equalized volume cut figure.

It is essential for the method that before the first cutting cycle ends, a new allocation is carried out, using the age and site classes presently in the second cutting cycle, and the ones falling into the third decade of the regulation. This way a gradual equalization of the volumes and cutting areas is brought about; thus a continuous trend towards normality can be achieved, with less sacrifice than it would be using a pure area regulation. (See detailed calculations in Table 19.)

TABLE 19

EXAMPLE OF AREA-VOLUME ALLOTMENT

| Type | Spec. Comp. | Site | Actual Area acres | R.F. | Actual Age years | Average Cut. Age years | Red. Acres | Actual Area Cut acres | Yield per Acre cu.ft. | Total Exp. Yield cu.ft. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FIRST CYCLE | | | | | |
| O.G.G. | HF | G | 159 | 1.118 | M | M | 178 | 159 | 13,493 | 2,145,387 |
| O.G.M. | CH | M | 671 | 1.093 | M | M | 734 | 671 | 13,193 | 8,852,503 |
| O.G.P. | CH | P | 164 | 0.711 | M | M | 117 | 164 | 8,518 | 1,406,792 |
| S.G.G. | FH | G | 805 | 1.751 | 70 | 75 | 284 | 162 | 8,476 | 1,373,112 |
| TOTAL: | | | | | | | 1,313 | | | 13,777,794 |
| | | | | | SECOND CYCLE | | | | | |
| S.G.G. | FH | G | 85 | 1.751 | 70 | 85 | 1,126 | 643 | 10,031 | 6,449,933 |
| S.G.M. | FH | M | 1,885 | 1.784 | 80 | 95 | 187 | 105 | 11,017 | 1,156,785 |
| TOTAL: | | | | | | | 1,313 | | | 7,606,718 |
| | | | | | REVISED ALLOTMENT | | | | | |
| | | | | | FIRST CYCLE | | | | | |
| O.G.G. | HF | G | 159 | 1.181 | M | M | 178 | 159 | 13,493 | 2,145,387 |
| O.G.M. | CH | M | 671 | 1.093 | M | M | 706 | 646 | 13,193 | 8,526,869 |
| TOTAL: | | | | | | | 884 | | | 10,692,256 |
| | | | | | SECOND CYCLE | | | | | |
| O.G.M. | CH | M | 671 | 1.093 | M | M | 28 | 25 | 13,193 | 329,825 |
| O.G.P. | CH | P | 164 | 0.711 | M | M | 117 | 164 | 8,578 | 1,406,792 |
| S.G.G. | FH | G | 805 | 1.751 | 70 | 85 | 1,410 | 805 | 10,031 | 8,074,955 |
| S.G.M. | FH | M | 1,885 | 1.784 | 80 | 95 | 130 | 73 | 11,017 | 800,584 |
| TOTAL | | | | | | | 1,685 | | | 10,692,256 |

(continued)

TABLE 19 (Continued)

EXAMPLE OF AREA-VOLUME ALLOTMENT

$$\text{10-year CUTTING AREA} = \frac{10{,}506}{8} = 1{,}313.25 \text{ acres}$$

$$\text{AVERAGE YIELD} = \text{A.C.} = \frac{13{,}777{,}794 + 7{,}606{,}718}{2} =$$

10,692,256 gross cu. ft./10 years

## CONCLUSION

Before considering the results obtained from this study, it must be emphasized that for practical allowable cut estimates a statistically-planned sampling to a required level of confidence would be essential.

When planning a more intensive inventory, data obtained with this small scale survey could be used profitably for the calculation of the necessary number of measurements in each phase, (number of point samples, number of increment cores, height measurements, etc.).

Further divisions of the present classes into more detailed age classes and stocking classes would also be advisable.

This thesis did not involve the calculation of actual sampling errors, as would be necessary for practical purposes. It simply stressed the importance of calculating and applying several allowable cut methods to a forest, and developing an inventory procedure, where the necessity of such allowable cut estimations arises.

This importance can be realized if we take a look at the final summary table of the allowable cut calculations (Table 20), where the calculated allowable cut volumes are presented in gross and net merchantable cubic feet. It was assumed that cuts would be taken from the old growth stands in the coming ten years and when calculating net merchantable volumes, corresponding merchantable reduction factors were therefore used. Factors are given in Table 14. It should be noted that no allowances have been made for research reservations or possible additions to the area of the Forest.

Except S. Petrini's two formulae - which are based on the same principles - all methods show different answers, caused by the difference in their basic assumptions, or by their application to a certain condition. Naturally in this case a simple statistical comparison of these figures would not be realistic. They have to be judged by considering many aspects of the prevailing forest management methods, present condition of stands, and possible future improvements. Most of these aspects were touched upon in the general description of the formulae and further elaborated and commented on in the discussions of the actual calculation.

Some points, however, need further explanation. It is seen from Figure 2 that volume distribution in the Research Forest is far from normal. The cruise data used in this study showed that old and second growth stands are overstocked, whereas the younger 20-30-year age classes are understocked by comparison with Fligg's (1960) estimates. (See reduced age distribution in the calculation of the Kemp III formula.) Obviously the objects of management will be to reduce these irregularities in the shortest time with the least sacrifice. Pure area regulation would be the easiest way to attain normality, but this would result in large harvest volume differences during the first rotation. Errors in the estimation of future yields could also appear from the determination of sites and areas of presently young, understocked stands. These stands, during the long estimation period, might not develop to the level of the empirical yields, as expected. These uncertainties naturally can be corrected and empirical yields exceeded by employing intensive silvicultural practices, together with regular checks on the stands, recurrent inventories, and by using short yield prediction periods.

In contrast to area regulation, volume methods will result in even yearly or periodic harvest volumes, but this way the trend towards a normal forest will slow down. For example, allowable cut volumes (Table 18), calculated from volume formulae, gave much lower estimates than are indicated for the first eight years in the area regulation method (see area regulation calculations).

It must also be noticed that formulae based on periodic annual increments show higher allowable cut volumes than formulae based on mean annual increment. These might be considered as slight overestimates, since if the young growth stands are presently understocked, it follows that their increment should not be allocated for cutting, rather, it should be considered on the account of stocking improvement.

TABLE 20

YEARLY ALLOWABLE CUT VOLUMES AS CALCULATED BY DIFFERENT FORMULAE AND METHODS

YIELD IN CUBIC FEET

| D.B.H. Limit in. | GROSS | NET | GROSS | NET | GROSS | NET | GROSS | NET | GROSS | NET | GROSS | NET |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area Regulation | | Austrian | | Hanzlik | | Kemp I | | Kemp II | | Kemp III | |
| 3.1 | - | - | - | - | 958,334 | 554,415 | - | - | - | - | - | - |
| 9.1 | 910,494 | 529,197 | 880,137 | 511,553 | 846,289 | 491,880 | 1,692,972 | 983,989 | 932,810 | 542,168 | 1,069,445 | 621,583 |
| 11.1 | 847,284 | 491,967 | 815,562 | 473,548 | 774,588 | 449,757 | 1,672,812 | 971,301 | 864,850 | 502,166 | 1,056,659 | 613,538 |
| 13.1 | 813,557 | 471,832 | 733,746 | 448,362 | 692,997 | 401,571 | 1,635,334 | 947,627 | 780,537 | 452,298 | 1,033,035 | 598,613 |
| | Barnes I | | Barnes II | | Hundeshagen | | H. A. Meyer I | | H. A. Meyer II | | Von Mantel | |
| 3.1 | 1,042,174 | 602,918 | 1,246,799 | 721,298 | 1,468,112 | 849,332 | 1,085,543 | 631,130 | 1,449,103 | 842,502 | 1,263,218 | 730,797 |
| 9.1 | 971,481 | 654,644 | 1,199,917 | 697,415 | 1,319,442 | 766,886 | 1,018,176 | 591,963 | 1,386,559 | 806,139 | 1,048,681 | 609,514 |
| 11.1 | 904,775 | 525,348 | 1,130,971 | 656,687 | 1,291,658 | 749,988 | 914,326 | 531,585 | 1,282,876 | 745,858 | 951,633 | 552,556 |
| 13.1 | 827,501 | 479,512 | 1,048,761 | 627,725 | 1,211,506 | 702,031 | 783,265 | 455,387 | 1,151,917 | 669,719 | 847,278 | 490,972 |
| | Grosenbaugh | | W. H. Meyer | | Petrini I | | Petrini II | | Black Hills | | Area-Volume Computation | |
| 3.1 | - | - | - | - | - | - | - | - | - | - | - | - |
| 9.1 | 1,502,849 | 873,486 | 1,603,836 | 932,181 | 1,462,456 | 850,009 | 1,462,249 | 849,888 | 1,077,848 | 626,467 | 1,035,783 | 602,018 |
| 11.1 | 1,203,778 | 698,962 | 1,321,528 | 767,332 | 1,219,892 | 708,318 | 1,218,306 | 707,397 | 1,005,804 | 584,010 | 960,000 | 557,414 |
| 13.1 | 1,035,659 | 600,133 | 1,142,362 | 661,964 | 1,063,511 | 616,273 | 1,060,924 | 614,774 | 932,861 | 540,565 | 884,205 | 512,370 |
| | Area-Volume Allotment | | | | | | | | | | | |
| 3.1 | - | - | | | | | | | | | | |
| 9.1 | 1,088,324 | 632,556 | | | | | | | | | | |
| 11.1 | 1,069,226 | 620,835 | | | | | | | | | | |
| 13.1 | 976,641 | 565,934 | | | | | | | | | | |

As a transition between the area regulation and the volume formulae, the area-volume control methods gave a more or less in-between answer concerning cutting volumes, simultaneously ensuring a continuous trend towards a normal forest.

In consideration of which method actually is to be used, the general objectives of management of any property must be known. For the University Research Forest, these were stated by the U.B.C. Forest Committee in 1959 as: "The University Forest is managed to provide a sustained and maximum income. This management is to be consistent with effective use of the property for teaching, demonstration, research, and public recreation. Income from the Forest will be used to maintain the capital value of the Forest in such a manner that these prime uses will be maximized."

Since all forest products from the University Research Forest are sold on the open market there is no need to consider the special problems that might arise if demands of a particular manufacturing plant had to be satisfied.

From the regulation point of view a decision should be made as to what level of cut can be sustained and at the same time provide a maximum income indefinitely into the future.

The high allowable cut values suggested by the Grosenbaugh, W. H. Meyer, H. A. Meyer II, and Petrini formulae are the result of application of approaches that are not suited to the present intensity of management of the Forest. Their application would assume salvage of dead trees and thinning regimes not yet practicable. The present large surplus of big trees makes difficult the application of systems based on diameter distributions. The period over which surplus volumes are to be harvested would depend very much on the objectives of management. It ranges from several decades to a whole rotation in different methods. From the economic point of view existing old growth volumes should be harvested as rapidly as possible to provide the capital for development of roads and improvement of amount and value of growth on the whole forest. This suggests the use of a short period of adjustment but requires careful planning of the transition from logging of old growth to logging of younger stands. In this regard the surplus of stands above rotation age will facilitate the transition and the road system developed for logging of old growth will provide an excellent basis for more intensive management of young stands.

It is obvious that without intensive management, average volumes harvested per acre must decrease. If intensive management can be justified economically and applied immediately, the level of cut eventually might approach that indicated by simple area regulation for the next two decades.

The most conservative formula (Hanzlik) allocates surplus growing stock over the rotation and uses mean annual increment at 80 years. These assumptions should be subject to review as conditions change.

It is obvious that none of the foregoing formulae or methods can be selected as absolutely correct. However, area-volume control methods seem to provide the most realistic approach as a compromise between pure area and volume approaches.

If the area-volume computation and the area-volume allotment methods are compared, the allowable cut obtained by the area-volume allotment will show a figure approximately 100,000 gross cu. ft. higher for the next decade. This presents the problem of choosing the level of cut which is better suited to the condition of the Forest. Before the final decision is made, the possible development of the 30-year-old stands on the Forest also should be discussed.

Parts of the Research Forest now covered by the presently 30-year-old stands were burned in the years 1925, 1926 and 1931 (Walters and Tessier, 1960). After the burning and until 1953, this area was left to Nature without any provision for artificial restocking. In 1953, forestry students planted a few acres of the understocked areas with Douglas fir, Scots pine and Norway spruce. Restocking to reasonably satisfactory levels, however, was completed in 1959, when the last large poorly stocked area was planted with 6,500 Douglas fir seedlings and 6,000 Scots pine seedlings on 117 acres. In all, more than 90,000 seedlings were planted on 700 acres. Stocking probably will continue to improve as a result of natural regeneration.

Because the A.&L. portion of the Forest is in the initial stages of planned management, there are still large areas which have volumes well below Fligg's (1960) empirical volume estimates, and their complete recovery cannot be expected within the coming 10 or 20 years. Although Fligg's data may be misleading because of curving at lower ages, the problem of indicated understocking remains. In spite of the efforts spent on regeneration, caution must therefore be used when calculating the allowable cut for the coming two decades. A supplementary volume regulation formula, which bases its estimate on actual volumes, may be used as a guide for the selection of a fairly safe allowable cut estimate from the two favoured area-volume method. For this purpose Von Mantel's formula should provide a reasonable comparison. Fortunately the allowable cut obtained by Von Mantel's formula is almost identical to that obtained by the area-volume computation method and thus verifies the final selection of the allowable cut indicated by the area-volume method.

Naturally, as time passes, more experience will be gained, more will be learned about the Forest and more intensive silvicultural and utilization techniques will be applied. Although rotation length has been assumed to average 80 years, this may not be optimum. It is hoped it can be reduced by improving standards of utilization and more intensive management. It is thus reasonable to expect that the growth and yield of the

Research Forest will increase. However, at the present stage a short prediction period and a method providing a moderately conservative allowable cut should be used.

When complete recovery of the presently understocked areas is assured, the use of the simpler area-volume allotment method may be more convenient. However, until then it would appear safer to use the area-volume computation method, which gives a lower allowable cut.

BIBLIOGRAPHY

Allen, R. H. Jr. and E. W. Morgen. Range mean ratio of basal area as an indicator of Bitterlich sampling intensity in lodgepole pine. College of Forest and Range Management, Colorado State University. Fort Collins, Colorado. Research Note No. 13. 2pp.

Allison, G. W. and R. E. Breadon. 1960. Timber volume estimates from aerial photographs. For. Survey Notes. No. 5. Department of Lands and Forests. Victoria, B. C. 25pp.

Bajzak, D. 1960. Forest inventory on aerial photographs of part of the University of British Columbia Research Forest, Haney, B. C. University of British Columbia, Faculty of Forestry. Vancouver 8, B. C. Unpublished report. 11pp.

_________. 1960. An evaluation of site quality from aerial photographs of the University of British Columbia Research Forest, Haney, B. C. University of British Columbia, Faculty of Forestry, M.F. thesis. Vancouver 8, B. C. 113pp.

Baker, F. S. 1960. A simple formula for gross current annual increment. Jour. For. 58(6):488-489.

Barnes, G. H. 1951. A new method of volume regulation. Jour. For. 49(4):272-277.

Bell, J. F. and L. B. Alexander. 1957. Application of the variable plot method of sampling forest stands. Oregon State Bd. of Forestry. Forest Research. Note 30. 21pp.

Briscoe, C. B. 1957. Stand table construction from relascope plots. La. Agr. Exp. St. Forestry. Note 15. 3pp.

Castles, J. R. 1959. Calculating allowable harvest cuts in the National Forests of the Northern Rocky Mountain Region. Society of American Foresters. Proceedings. Society of American Foresters meeting. Mills Building, Washington 6, D.C. pp.109-151.

Chapman, H. H. 1950. Forest Management. The Hildreth Press Publishers. Bristol, Conn. 582pp.

Cunia, T. 1959. Notes on cruising intensity by the Bitterlich method. Jour. For. 57(11):849-850.

Davis, K. P. 1954. American Forest Management. McGraw-Hill Book Co. Inc. Toronto. 482pp.

Fekete, Z. 1950. Erdorendezestan. Agrartudomanyi Egyetem Erdo- es Foldmernoki Kar. Sopron. Hungary. 133pp. Mimeo.

Fligg, D. M. 1960. Empirical yield tables. Forest survey notes. No. 6. British Columbia Forest Service, Department of Lands and Forests. Victoria, B. C.

Greeley, A. W. 1935. Development of management plans on Snoqualmie National Forest. Yale University. School of Forestry, M.F. thesis. 155pp.

Grosenbaugh, L. R. 1952. Plotless timber estimates...new, fast, easy. Jour. For. 50(1):32-37.

_______________. 1955. Better diagnosis and prescription in Southern Forest Management. Southern For. Expt. Sta. Occasional paper. 145. 27pp.

_______________. 1958. Allowable cut as a new function of growth and diagnostic tallies. Jour. For. 56(10):727-730.

_______________. 1958. Point-sampling and line-sampling: Probability theory, geometric implications, synthesis. Southern For. Expl. Sta. Occasional paper. 160. 34pp.

Gross, L. S. 1950. Timber Management Plans on the National Forests. U. S. Dept. of Agr. Washington 25, D.C. 59pp.

Hanzlik, E. J. 1922. Determination of the annual cut on the sustained basis for virgin American forests. Jour. For. 20(6):611-626.

Hough, A. F. 1954. The control method of forest management in an age of aerial photography. Jour. For. 52(8):568-574.

Hughes, W. G. 1956. Management plan considerations in initiating sustained yield forestry. The Empire Forestry Review. 35(1):29-35.

Jerram, M. R. K. 1945. A Textbook on Forest Management. Chapman and Hall Ltd. London. 154pp.

Johnson, F. A. and V. E. Hicks. 1956. Estimating allowable cut without a type map in forests of Western Washington and Western Oregon. Jour. For. 54(8):522-524.

__________. 1961. Standard error of estimated average timber volume per acre under point sampling, when trees are measured for volume on a subsample of all points. U. S. Dept. of Agr. Pac. Northern For. and Range Expt. Sta. Res. Note. No. 201. 5pp.

Kendall, R. H. and L. Sayn-Wittgenstein. 1959. An evaluation of the relascope. Canada Dept. of Northern Affairs and Natural Resources. For. Research Div. Tech. Note. No. 77. 26pp.

Ker, J. W. 1953. Growth of immature Douglas fir by tree classes. For. Chron. 29:367-373.

__________. and J. H. G. Smith. 1957. How much and how fast -- forest measurements today. British Columbia Lumberman. February and March. 6pp.

__________, J. H. G. Smith, and J. Walters. 1957. Observations on the accuracy and utility of plotless cruising. British Columbia Lumberman. November. 2pp.

Littleton, D., A. Strother, H. Eidsvik and T. Jeanes. 1957. Re-appraisal of the allowable annual cut on the U.B.C. Research Forest, Haney, B. C. University of British Columbia, Faculty of Forestry. Vancouver 8, B. C. Unpublished report. 6pp.

Meyer, H. A., A. B. Recknagel and D. D. Stevenson. 1951. Forest Management. The Ronald Press Co. New York. 290pp.

__________. 1952. Structure, growth and drain in balanced uneven aged forests. Jour. For. 50(2):85-92.

__________. 1952. Accuracy of forest growth determination based on the measurement of increment cores. Agr. Expt. Sta. State College, Pennsylvania. Bulletin 547. 25pp.

Meyer, W. H. 1943. Amortization in stand growth and depletion problems. Jour. For. 41(12):920-922.

__________. 1952. Regulation of cut in immature understocked forests. Jour. For. 50(12):934-939.

Petrini, S. 1956. Determining the possible yield. Bulletin No. 21. Royal School of Forestry. Stockholm, Sweden. 9pp.

Recknagel, A. B. 1917. The theory and practice of working plans. John Wiley and Sons. New York, N. Y. 265pp.

Robertson, R. C. and J. N. MacFarlane. 1960. Growth in volume and value on the U.B.C. Research Forest during the next decade. University of British Columbia, Faculty of Forestry. Vancouver 8, B. C. Unpublished report. 13pp.

Sammi, J. C. 1961. De Liocourt's method modified. Jour. For. 59(4):294-295.

Smith, J. H. G. 1952. A critical appraisal of methods of forest regulation. Yale School of Forestry, Directed Study. 146pp. typed.

______________, and J. W. Ker. 1957. Timber volume depends on $D^2H$. British Columbia Lumberman. September. 2pp.

______________. 1958. Management planning and determination of the allowable cut in forests of the United States and Canada. The Empire Forest Review. 37(91):43-48.

______________, and J. W. Ker. 1959. Empirical yield equations for young forest growth. British Columbia Lumberman. September. 2pp.

______________, J. W. Ker and J. Csizmazia. 1961. Economics of Douglas fir, western hemlock and western red cedar in the Vancouver Forest District. The University of British Columbia. Vancouver 8, B. C. Forestry bulletin No. 3. 144pp.

Spurr, S. H. 1952. Forest Inventory. The Ronald Press Co. New York, N.Y. 476pp.

____________. 1954. Simplified computation of volume and growth. Jour. For. 52(12):914-922.

____________. 1960. Photogrammetry and photo interpretation. Second Edition of Aerial Photographs in Forestry. The Ronald Press Co. New York, N.Y. 472pp.

Stage, A. R. 1959. A cruising computer for variable plots, tree heights and slope correction. Jour. For. 57(11): 835-836.

Stage, A. R. 1960. Computing growth from increment cores with point sampling. Jour. For. 58(7):531-533.

The Western Forestry and Conservation Association. 1950. Reports of the West Coast Forestry Procedures Committee on various recommended practices and techniques. Portland, Oregon.

University of British Columbia Research Forest Committee. 1959. The first decade of management and research on the U.B.C. Forest, 1949-1958. University of British Columbia. Vancouver 8, B. C. 82pp.

University of British Columbia Forest Club. 1959. Forestry Handbook for British Columbia. Second edition. University of British Columbia Forest Club. Vancouver 8, B. C. 800pp.

U. S. Dept. of Agriculture. 1958. Explanatory notes on the allowable cut task force report. Forest Service, Washington, D.C. 63pp.

Walters, J. and J. P. Tessier. 1960. U.B.C. researchers put "A.&L." back in production. British Columbia Lumberman. December. 3pp.

Yoder, R. A. 1961. Accumulation and processing data for decision making in forest management. Proceedings. Sixteenth Yale Industrial Forestry Seminar, Oregon State College. Corvallis, Oregon. 12pp.