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SOME PROBLEMS OF FOREST MENSURATION IN ALBERTA

by

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INTRODUCTION

This problem analysis has been prepared to assist in drawing up specific project plans, and to encourage discussion on forest mensuration in general.

According to Bruce and Schumacher (1934): "Mensuration is a means not an end. It is an indispensable aid to solving of problems in management, finance and silviculture." Forest mensuration is most intimately bound with statistical analysis. As Smith and Ker (1957) point out, there is a need for greater liaison between the fields of forest mensuration and statistics, yet there are problems unique to the field of forestry that must be considered logically as well as mathematically: hence, the field of forest mensuration.

The duties of a forest mensurationist in the Calgary District Office of the Department of Forestry as defined by an information circular are as follows:

"To participate in planning research projects, especially the mensurational and statistical aspects such as sampling techniques and experimental design. For the Alberta position this will involve studies of growth and yield in relation to ecological factors, techniques for predicting density development in lodgepole pine".

Further elucidation of forest mensuration is gained from a recently established forest mensuration group composed of C.I.F. and S.A.F. members as outlined by Young (1962). Honer and Sayn-Wittgenstein (1962) in a report of the committee on forest mensuration problems included these comments from the group:

1. Forestry has been slow to accept and develop better methods for forest measurements. As one respondent replied, "We are still using chains and abneys to obtain tree heights - a slow process in this day and age when we are able to obtain pictures of the back of the moon by remote control".
2. The report continually reiterated the charge that there was a lack of development of basic theory and technique for explaining and measuring such things as growth, silvical responses and environmental factors. "We were told to return to a careful evaluation of biological phenomena and to have less belief in all statistical and computer approaches." "We must attempt to understand and explain the relationships of growth to environmental complexes and individual factors such as age, species, stand density, and many other factors".
3. "The gap between mensurational capabilities and field knowledge hence field application, is so great in many instances that advances in technique roughly called forest mensuration are not benefiting the practicing forester".

ALBERTA PROBLEMS

There are indications that a revival of interest in forest mensuration is taking place, but there are differing points of view concerning its objectives. During recent familiarization trips in Alberta comments from foresters working for the provincial government and industry showed interest in the following subjects.

1. Mr. R. D. Loomis (Forester in charge of the Alberta forest management branch) and his staff desired:

a. The development of volume tables for the sale of standing timber, especially white spruce. This problem was discussed by the Rocky Mountain section of the Canadian Institute of Forestry (1961). The main problem for the Alberta government is the collection of dues from the sale of timber on crown lands. This problem is not unique to Alberta, nor is it a new one. Many other provinces have adopted log scaling as an alternative. It is not just a question of tree volume tables but of sampling to determine tree form, cull and other variables.

b. A test on point sampling for forest management timber cruising. A joint program of testing and developing has been verbally agreed upon. A master's thesis on point sampling has been prepared by the author (1961). Appropriate angle gauge sizes and sampling designs for various purposes still have to be selected for Alberta.

c. A study of sampling methods to determine the adequacy of regeneration after various disturbances. As management becomes more effective, an essential part of control will be the assessment of regeneration on cut-over lands.

d. A method to determine the effect of SO_2 on tree growth was requested. This matter has been dealt with in recent correspondence on the subject. Until more is known about the problem, little can be done on appropriate sampling techniques. Studies at Trail, B.C. and other areas where SO_2 damage has occurred show that incipient damage is difficult to detect, therefore, a single-tree approach rather than plots which may tend to average out more than they reveal is suggested. Correlations between sulphur content in the foliage and SO_2 concentrations in the air may also be made. Some controversy exists over the means of finding SO_2 concentrations in the air, since the Alberta government in Edmonton and the Federal government in Ottawa have obtained different results. Federal Forest Pathologists called in several years ago on this same question reported reddening of trees they observed to be ("red-belt"), a condition resulting from rapid thaws and freezing during the winter. A field trip with Mr. Dennis Couvin was made regarding this problem and no apparent damage near the sulphur recovery plant at Coleman could be observed. Samples of foliage on selected trees were collected for sulphur determinations in the foliage. It was reported that some valleys of timber near oil well heads were reddened, but this was not observed by the author.

2. Mr. R. Steele (Forester in charge of the Alberta forest inventory branch) had no specific requests. Point sampling techniques used in inventory sampling have not been tested by them, and interest in tests and development was shown.

3. Mr. D. I. Crossley (Chief Forester for North Western Pulp and Power Limited), was interested in a study of form class in older stands. He felt that form class increasing with age in lodgepole pine stands was causing yields to be higher than anticipated. An assessment of rotation ages for lodgepole pine was also discussed. Analysis of their continuous forest inventory data indicated rotation ages of 70 to 80 years to be most desirable for maximum fibre production. No guarantee at present can be given on the time required to obtain adequate regeneration, and management planning to date is essentially on a volume control basis. Therefore, yield table predicting methods are somewhat premature. The development of aerial photo volume tables is being carried out by this company.

4. Mr. Herman Oosterhuis (Forester for the Muttart Tree Farm) was most interested in an inventory and management system for this small tree farm (20 square miles). The intention is to encourage white spruce sawtimber production on the area with stand improvement work, such as the removal of an aspen overstory. Some suggestions on the use of point sampling for silvicultural prescription were given in correspondence with

Mr. Herman Oosterhuis. A memorandum to Mr. J. L. McLenahan contains some proposals for the study of stand treatments presently being applied on the area.

5. In addition, there are forest mensurational problems needing further study to assist research workers within the Department of Forestry. Co-operative studies might be undertaken on the following:

1. growth and its relation to ecological factors.
2. cull and volume.
3. common problems of experimental design and statistical analysis.
4. sampling techniques.

Problem areas to be discussed in this report are categorized under the following headings: volume tables, sampling, inventories, growth and yield, computer programs, experimental design and instrumentation.

VOLUME TABLES

Considerable confusion still exists on volume tables. At present, a large number of published standard tables may be used, and a great deal of personal bias appears to enter into their selection. There is disagreement on volume tables within organizations of a province, let alone between provinces.

The Alberta Department of Lands and Forests, Forest Surveys Branch, has recently published "Form class volume tables for white spruce and lodgepole pine in Alberta" Anon. (1962A). They contend that these tables were necessary because previously published standard volume tables by the Department of

Forestry "Form-class volume tables", second edition Anon. (1948), Blyth (1952) (1955) did not meet their needs. They wanted board-foot and form-class tables based on a 5/16-inch kerf and the International log rule. Blyth's tables were based on the Scribner rule and presumably a ¼-inch kerf.

The determination of form-class for a stand is a difficult measure to obtain, and the author remains to be convinced that present methods of determining form-class in Alberta improve stand volume estimates. Tests on this aspect could clarify the situation. Multiple correlation analyses of all factors affecting tree volume should be undertaken so that foresters clearly understand how much they are improving their volume estimates by the addition of variables such as form-class.

The preparation of volume tables using free hand and harmonized curves is questionable, and better methods employing electronic computers are now available. Volume formulae instead of tables should be developed because they require no tedious interpolation and may be more easily plugged into machine data processing. Studies by Kirby (1960) and Golding and Hall (1961) indicate volume formulae to be as good or better than volume tables.

The adoption of the cubic foot rule as the standard for volume determinations has been an ideal set forth by many foresters (Ker. 1962). Like the metric system it is far from a reality, although one province (British Columbia) has adopted the measurement of timber in cubic feet exclusively. Great Britain is attempting a slow conversion to the metric system for convenience in the European Common Market. Recent published volume tables for British Columbia, Browne (1962), are for total cubic feet only, with percentage correction factors for various utilization standards.

An interesting coincidence is that their volume table approach (using a tree volume formulae, total cubic foot volume, and percentage corrections for various utilization standards) is similar to the ideas advocated by Kirby (1960), except that the British Columbia tables are based on a logarithmic tree-volume equation as advocated by Schumacher and Hall (1933). More recently, many investigators, including Spurr (1952), Smith and Ker (1957A), Kemp (1957a) (1957b) and Golding (1960), have found the use of D^2H more applicable than logarithmic equations.

The possibilities of using a composite volume table as suggested by Gevorkiantz and Olsen (1955) should also be investigated. He found that in the Lake States there was as much variation of volume in tables for one species as there was between species. Therefore, he advocated a composite table. In going over total cubic feet volume tables for the sub-alpine region of Alberta, it was found that there was close agreement with Gevorkiantz's composite table, which is based on a formula that states total cubic foot volume of a tree to be 42 per cent of the volume of a cylinder of equivalent height and diameter. Lodgepole pine was slightly higher and Douglas fir slightly lower than the composite table.

Many thousands of tree measurements suitable for the preparation of standard volume tables are already available; therefore, the problem is not so much obtaining more measurements as analyzing measurements already taken. Top priority should be given to studies that will lead to a nationally recognized set of volume formulae. This would make calculations for a national forest inventory and for forest research much more comparable. From recent correspondence, Mr. Bickerstaff has indicated that measurements taken by A.W. Blyth for tree volume studies "were now transferred to I.B.M. cards for future volume studies". Mr. T. Honer has stated that he is working on the problem. Co-ordination of activity between head office and district offices on the approaches to be taken with volume formulae might be desirable. Separate volume tables or formulae for every species in every province do not seem necessary. White spruce, for example, is not so different throughout its range in the boreal forest as to necessitate the many volume tables constructed for it. It is well, therefore, that the preparation of volume formulae has been undertaken by head office. Forest mensurationists in district offices could do the applicability tests and establish uniform procedures for drawing up local tables.

A major limitation of any standard volume table or formula approach will always be the assumption that the trees selected for analysis are representative. At best, a standard volume table or formula can only be a good average, and its success depends upon proper application. It also must be remembered that, while the standard error of estimate for many volume tables or formulae is approximately ± 10 per cent for estimates on one tree, this error is reduced to ± 1.0 per cent when the combined volumes of 100 trees are determined.

SAMPLING

In sampling, the line between mensuration and statistics becomes indistinct. The basic theory of sampling is well established in statistical texts such as Cochran's (1959), but much remains to be done in forestry in describing the sampling distributions and objectives of various sampling designs. Coupled with sampling are the problems of defining the universe being sampled. The ultimate objective of sampling is not to obtain isolated examples but to yield results that may be related to a universe of some practical significance. The principal steps in a sample survey are as follows (Cochran, 1959):

1. Statement of the objectives of the survey - many surveys would not be necessary if an objective look at the probable results and the need for such results were taken.
2. Definition of the population to be sampled. The definition of the population is not always easy.
3. Determination of data to be collected.
4. Methods of measurement.
5. Choice of sampling unit.
6. Selection of the sample.
7. Organization of the field work.
8. Summary and analysis of the data.
9. Information gained for future surveys.

Sampling may reduce costs and give greater speed, scope and accuracy in obtaining information.

1. Plot and point sampling

Plot sampling has been traditional in forestry. In the past, the philosophy regarding plot sampling must have been controlled by some god of forestry who said, "Let there be plots"..... and thousands of plots have been established for better or worse. Ilvessalo (1932) pointed out that a great majority of plots established in Finland are of no scientific importance, because the methods used have proved defective. The validity of conclusions from experimentation depends just as much upon the original design and placement of the plots or more than it does on the adequacy of measurements obtained. Re-appraisal could perhaps be taken of some traditional plot studies in the Calgary district office.

Point and line sampling are now replacing plot sampling in many instances in forest management and for some uses in forest research (i.e. decay, and growth and yield studies). For forest management and research what is usually needed is detailed information about the several elements in the growth process: which size classes, vigor classes and species are growing the most rapidly; what losses are caused by insects, disease, windfall and suppression; and what portion of growth is being nullified by mortality.

2. Single-tree data

Three main advantages of single-tree data are as follows (Osborne 1949):

1. The methods using single-tree data are flexible and can include changes in the growth curves, as these might be brought about by changes in stand density and average tree size.
2. Changes brought by partial cutting can be evaluated since not only is the volume removed known, but also the species and tree classes.
3. Specific description of the trees that die during the remeasurement cycle may also be given.

Limitations to growth estimates using individual-tree data as obtained from point sampling are as follows (Kirby, 1961):

1. Newly qualifying trees at the time of remeasurement will make point samples from the same sample centre not exactly comparable.
2. Distinctions made from boring done in newly qualifying trees between ingrowth (those trees that were below measurable diameter) and larger trees, which, because of increased size, are included in the point sample, will have to be made for any detailed analysis of growth.
3. Some trees that should have been included in the point samples will never be tallied because of mortality.

Grosenbaugh (1955) favors dealing with only those trees sampled in the initial tally. The determination of survivor growth, mortality and cut for a single growth period is based on observations taken on the same trees at the beginning and at the end of the period.

3. Random or mechanical sampling

Random or mechanical sampling may be used for many forestry surveys. Hasel (1938) pointed out that in volume sampling it is necessary to make a compromise between what is theoretically correct and what is practically possible, while Schumacher and Chapman (1948) state that the importance of random selection is in the fact that the sample supplies all the information necessary to evaluate its own accuracy. Eminent statisticians like R.A. Fisher would most certainly agree that random sampling is essential for proper statistical analysis of the sampling. On the other hand, Meyer (1949) found the accuracy of a systematic cruise to be generally higher than that of a random cruise of the same intensity. Seely (1961) reports costs to be reduced by systematic sampling and that no consistent bias with systematic sampling is evident in volume sampling. Shiue (1959), Shiue and John (1962) offer a compromise approach with systematic sampling and multiple random starts.

4. Sample distribution

Little is known about the sampling distribution involved in forestry data. For example, Smith and Ker (1957B) on the examination of volume data presented by Johnson and Hixon (1952) on old growth Douglas fir show the frequency distribution of volume ranges from nearly poisson on .025-acre plots to approximately rectangular on 1.0 acre plots. Palley and Horwitz (1961) working with point sampling found the correlation coefficient between point sample estimates of number of trees and of basal area to be sensitive to the changes in tree arrangement and size, they state : "This correlation measure warrants further investigation as a means of qualifying differences in the spatial distribution of trees.

In regeneration surveys the study of the sampling distributions involved are relatively untouched.

5. Size and Shape of samples

The size of the sampling unit has been studied by Bickerstaff (1947a) and Clark (1953). They found that fifth-acre plots were most efficient in sampling stands with less than 1000 trees per acre. Mesavage and Grosenbaugh (1956) found that the sampling error was reduced as plots were made smaller and more numerous, although cost increased. In homogeneous and dense even-aged stands they found that plots even smaller than a tenth-acre might be most efficient. For cruises of very sparse, scattered, large timber they found 0.8 acre plots were more efficient than smaller ones. In point and line sampling, the size of the angle gauge is the important factor in sampling design.

Plots may be circular, rectangular or square. Horizontal distances are always measured so that plots on a slope have a greater surface area than plots on a flat. It is assumed that the equal air space above the plot is estimated by horizontal distance, although the relationship between growth and slope area is not clearly understood. Circular plots are more convenient if the plot size is less than $\frac{1}{4}$-acre (Anon. 1959B). Rectangular plots are sometimes preferred in volume sampling because, if any stratification occurs in the stand, the rectangular plots are more likely to include this stratification when they run with their long axes at right angles to the stratification and give a lower standard error of the estimate according to Shiue, Kozlowski (1962). This is particularly important in mountainous areas where slope has a tremendous effect on timber quality.

Circular plots are now widely used. The main advantages are that they require only one stake, are apt to have fewer borderline trees (because there is less perimeter) and take less time to establish if the stands are not too dense.

Bryan (1956) presents a simplified method of correcting for slope on circular plots. Circular plots projected vertically from the horizontal to a slope become elliptical, with the long axis running up and down the slope. He presents a different approach to slope correction: instead of measuring an elliptical plot on the slope, a circular plot with a fixed radius is used. He suggests the following formula where measurement of plot radius is in feet and plot slope is in degrees:

A = horizontal area of plot

D = plot slope in degrees

r = radius of sample plot

$$r = \sqrt{\frac{A \ 43,560}{\pi (\text{Cos } D)}}$$

6. Cluster sampling

The clustering of samples to form one sampling unit is another problem that needs further study. Meyer (1949) thought that, unless acre sampling units were dealt with, a greatly exaggerated value of the coefficient of variation would be obtained. The Intermountain Forest and Range Experiment Station Anon. (1962C) working with point samples has concluded that ten or sixteen sub-samples with a basal area factor of 75.625 and fixed area plots of 1/250th of an acre on an acre plot is an efficient sampling design for the purposes of their forest management. For an extensive inventory sampling design in southeast Texas using a three-mile grid for sample locations, Grosenbaugh and Stover (1957) found three point-samples per cluster using a basal area factor of 10, to be most efficient. Cluster sampling is becoming increasingly important for many forest surveys.

In determining the optimum number of plots in a cluster comprising a day's work for one field crew, the variation within and between plots is calculated. From time records, a ratio of time required to establish a plot at a new location compared with the time required to establish an additional plot at a location already occupied is computed. The analysis of variance may be represented as follows (Hasel, 1950):

Source	Degrees of freedom	Variance
Between units	n - 1	RA + B
Within units	n(k - 1)	B
Total	nk - 1	

n = number of sampling units,

k = number of plots per sampling unit.

By analysis of variance, it is then possible to determine the value of A and B. Then, if r is taken as the ratio of time, the optimum number of plots, n, in a sampling unit will be:

$$n = \sqrt{\frac{rB}{A}}$$

Grosenbaugh and Stover (1957) present the following calculation:

VB = Variance between locations

VW = Variance within locations

EB = Total cost per location

EW = Expense within cluster

Points per cluster or $n = \sqrt{\frac{VW}{VB} \cdot \frac{EB}{EW}}$

7. Number of samples required

With an estimate of the standard deviation which is dependent on stand homogeneity, sampling design, and precision of measurement, it is possible to calculate the number of samples required to attain a certain accuracy. The usual calculation, where an infinite number of samples may be taken, is as follows:

$$N = \frac{\sigma}{\sigma m}\ 2$$

N = required number samples;

σ = estimate of condition class variation with specified sampling procedures;

σm = required accuracy within one or two standard deviations of the mean (sampling error).

Hasel (1950) describes how to allocate the number of samples to various condition classes within a sampling unit, so that the best overall accuracy from a given amount of sampling may be obtained as follows:

A_i = acres in the i^{th} class

pi = proportion of total area in A_1

si = standard deviation

n = total number of sampling units to be apportioned

n_i = number of sampling units that should be taken in the i^{th} class

the $n_i = \frac{n(p_i s_i)}{p_i s_i}$. For application of this method, the reader is referred to the Forestry Handbook for British Columbia (Anon. (1959a).

Another possibility, according to Hasel (1950), is to convert individual sample volumes and growth expectations into dollar values and to calculate the standard deviation and averages based on value. Then, the allocation of samples using the method previously described could be on the basis of value instead of volume, thereby concentrating more effort on the high dollar value areas. Values and volumes do change with time and one must take this into consideration when permanent sampling units are being established.

REPEATED FOREST INVENTORIES

Relating one forest inventory to those succeeding is important if they are to be of any value as yardsticks of growth and depletion.

The idea of continuous forest inventory as a method of control for selection forest management in uneven-aged stands was first advocated by A. Gurnaud, applied by H.E. Biolley (1920) and reported by Knuckel (1953). Here a 100 per cent tally of trees was made at repeated intervals to show the condition of the forest resulting from stand treatment.

Since 100 per cent tallies are difficult to obtain on large properties, foresters on this continent have concentrated their effort on sampling. If the same samples are measured each time, the sampling errors for these areas is reduced to zero and the difference between the two measurements is a measure of growth on those sample areas, affected only by the accuracy of the measurements themselves. This is well illustrated by Bickerstaff (1947B). He gives an example for 10 paired plots as follows:

Calculation of Growth by Permanent Plots
Remeasured at a 5-year interval

Plot Number	Volume in hundreds of cubic feet per acre		
	1940	1945	Increment
1	48.2	50.5	2.3
. . . . . .	. . .	. . .	. . .
10	33.5	38.9	5.4
Total	387.9	428.4	40.5
Number	10	10	10
Average	38.79	42.84	4.05
Sum of Squares			182.85
$(\text{Total})^2/n$			164.02
Sum of deviations squared			18.83
Standard deviation			1.45
Standard error			0.46
Standard error as a per cent			11.4

The standard error of increment from paired plots = 0.46. The standard error of each measurement of the ten plots is approximately as follows:

$$\sqrt{S.E.^2} + \sqrt{S.E.^2} = 0.46$$

$$S.E._1{}^2 + S.E._2{}^2 = 0.2116$$

but since $S.E._1$ and $S.E._2$ are practically equal, then a reasonable approximation

$$S.E._1{}^2 \neq \frac{0.2116}{2} = 0.1058$$

$$S.E._1 \neq \sqrt{0.1058} = 0.325$$

For the ten plots, the observed standard error in the yield was 2.45 (known standard deviation of unpaired plots). The number of plots required to obtain a standard error of 0.325, using theorem that the standard error varies inversely with the square root of the number of measurements, will therefore be

$$\text{Number} = \left(\frac{\text{known standard deviation}}{\text{required standard error}}\right)^2 = \left(\frac{2.45\sqrt{10}}{0.325}\right)^2 = 569 \text{ plots}$$

Then, for this particular example, it would be theoretically necessary to measure over 500 temporary plots to equal the accuracy of increment obtained from ten paired plots.

Spurr (1952) points out that, regardless of how accurately temporary sample plots are measured, two successive volume inventories based upon them cannot yield a very precise estimate of growth because of the sampling errors involved. He gives as an example two repeated cruises with a standard error of $\pm$ 10 per cent:

1st cruise 4000 ± 400 bd. ft.

2nd cruise 5000 ± 500 bd. ft.

Growth equals 1000 bd. ft. but the standard error of the difference equals 640 cubic or ± 64 per cent.

Hall (1959) showed that, on a fifty-five acre woodlot, growth estimates over a nine-year period based on 75 permanent fifth-acre plots were ± 33.26 bd. ft. and that 216 temporary plots would have been required to give the same accuracy. On a 90,000-acre forest, 254 permanent plots gave a precision that would have required 3,970 temporary plots. In addition, Hall (1959) points out the dangers of expressing sampling errors of growth in per cent. "A percentage standard error of an average growth figure may easily be greater than the percentage standard error of the first or second inventory used in the growth calculation, whereas absolute figures will show the reverse relationships". Meyer (1953) also advocates periodic inventory with permanent plot sampling. He states that the advantages are:

a. to check on past mistakes.

b. to perfect current practices.

c. to determine a cutting budget.

d. to predict the effect of cutting on the development of forest resources.

e. to provide basic data for new developments.

Meyer (1960), gives his impressions on industrial forestry in southeastern United States: "A pattern is emerging which involves a light sampling by permanent plots for general control and planning purposes, supplemented by a reconnaissance of one kind or another for the portion of the forest area proposed for operations for the coming year".

Crossley (1959), reporting on continuous forest inventory and its relation to forest management at North Western Pulp and Power Ltd. in Alberta, hoped that aerial stand volume tables would eventually replace many of their permanent "continuous forest inventory plots" .

The widespread use of continuous forest inventory based on permanent sample plots on the North American continent is largely attributable to the zeal of Cal Stott (1939) (1947) of the United States Forest Service. The system has been applied to both even and uneven-aged types of management.

Points of reference that should be considered before any continuous forest inventory system is applied are as follows (Davis, 1955):

1. C.F.I. is usually associated with some stability in forest production where the initial stages of forest management have been passed. The first job of forest management in bringing previously unregulated forests under some sort of management is usually not so much concerned with growth or total growing stock, but with stand improvement, silvicultural questions and bringing about an age class distribution that sustained yield can be planned upon. The key question of management in its initial stages is, "How much can we cut and where?" This is answered by having some knowledge of the mature and nearly mature stands. How much is cut is largely a managerial decision and is usually not related to growth.
2. Because of the light sampling usually employed (less than

one per cent), C.F.I. does not locate stands of timber to be cut and is not a basis for operational planning.

3. There is the possibility of the permanent plots being treated in a biased manner and thus not presenting a representative sample of changes brought about by cutting.

4. The advantages of stratification by size classes, species composition, density, and merchantability classes are not utilized when a grid of plots covering the whole area is used.

5. C.F.I. does provide a birdseye view of a forest property and may be used as a basis for overall management decisions.

Recently, "continuous forest inventory" systems relying on a grid of permanent plots to assess changes in forest conditions have been challenged by Ware and Cunia (1962), who found from their studies that more efficient sampling designs could be brought about by replacing some of the permanent plots with temporary plots. The ratio of permanent to temporary plots required is dependent upon the correlation of successive surveys and on the cost ratio of permanent and temporary plots. It is interesting to note that this monograph on sampling is the product of two authors working independently, but who arrived at more or less similar conclusions. Mr. K.D. Ware was working on his thesis for his doctoral dissertation and was employed by the U.S. Forest Service. Mr. T. Cunia is on the operations research staff of Canadian International Paper Co., Montreal, Quebec.

Hagber (1960), professor and acting director of the forest research institute of Sweden, presented a paper on Sweden's approach to a national forest inventory. The present method of forest inventory in Sweden has to account for the balance between timber depletion and the increment of forest capital. The essential feature of the method is that yearly statements for all of Sweden's forested area are obtained by sampling the whole area with one-tenth of the sampling intensity. At the end of ten years, the sampling is combined and allowances for depletion and growth are made to give the most accurate picture of forest inventory every ten years. Hagber (1960) states, "If a true national forest survey is required instead of a number of provincial inventories, the survey should be carried out in the whole country annually."

Morris (1962) points out that there is still variation in inventory methods of the forest regions of the U.S. forest service. "We have no desire to discourage initiative through excessive standardization requirements." The items which are most likely to develop toward national standards are:

1. plan document size
2. terminology
3. units of measure

Some standardization of sampling technique for the purposes of forest management is taking place in national forests. This is point sampling with ten point samples (sub samples) mechanically spaced over an acre at each sample location. Area condition classification as developed by Austin Hasel and Robert Larson is also employed. Morris (1962) states, "Timber management planning on national forests has been in a state of evolution for the past 50 years and, no doubt, will continue so for at least an equal period of time."

Canada has made gains in forest management with the completion of provincial forest inventories. The job of improving forest inventory techniques and applying the information to forest management remains to be completed. This field could well occupy a forest mensurationist's time completely, with a program of basic and applied research.

GROWTH AND YIELD

1. Yield tables

Probably one of the most controversial endeavors of foresters is the preparation of yield tables. Briegleb (1950), reporting on the future of yield tables in the United States, says that in the past thirty to forty years foresters have constructed yield tables of one sort or another for most of the important pure even-aged types in the U.S.A.. A few have been constructed for mixed and uneven-aged stands. The yield tables constructed to date have a wide range of technical adequacy and application tests have been completed on only a few. He questions the task of making the necessary application studies, modifications, or the construction of new tables. He states that yield tables for managed second growth stands are much better than yield tables for unmanaged stands. For uneven-aged and mixed stands that are likely to have a short cutting cycle, he states that growth estimates are far more easily obtained by stand table projection methods or by permanent growth plots established on the area.

In addition, Briegleb (1950) felt that yield tables were of little help in answering the following questions:

1. What timber volumes should be maintained to obtain maximum growth?
2. What should the tree distribution be in uneven-aged management by size and age classes?
3. Is even-aged management more productive than uneven-aged, and if so on what sites?
4. What species composition will produce the greatest increment on various sites?
5. At what rate should the transition from existing to desired growing stock be made in order to maximize growth?

Davis (1958) points out that much of present forest management is being organized over extensive areas of hitherto unmanaged stands. The need of forest management is to put first things first and to do the obvious and possible in building roads and cutting where it is most important. Davis goes on to say that growth calculations for unmanaged forests are at best uncertain and not too meaningful. The importance of growth in forest management is yet to come; immediate emphasis on it is out of perspective. Other criticisms by Davis (1958) of yield tables are as follows:

1. Permanent growth plots are expensive and time-consuming.
2. The future may render any past growth data partially inapplicable, because of stand improvements and other changes.
3. Sampling intensities are low so the application must be to large areas.
4. There is considerable rigidity inherent in the approach.
5. In many regulatory situations, especially when dealing with establishment of initial management control, little direct

use is made of growth data.

6. At the present level of forest management on the North American continent, desirable stocking conditions are seldom found in nature. One is either building up poorly stocked stands or making initial cuts in mature stands.

Yield tables constructed from temporary plots or from a single measurement of permanent plots have four major weaknesses:

1. Climatic variations and their effect on growth are not considered.
2. The approach of stands in understocked and overstocked conditions toward normality is not measured.
3. Once stands are managed, empirical or normal yield tables are of little value, because each time a tree is cut growing conditions are changed.
4. Prediction of stand development based on temporary plots is uncertain.

The author, in a study of forest management plans for national forests of the United States, found that yield tables were little used in management planning. Management was aimed mainly at bringing about desirable age class distributions and at stand improvement. The same may be said for many forest management plans in Alberta.

2. Thinning and spacing studies

Following is some literature that should be taken into consideration before new thinning and spacing projects are established.

Craib (1947) showed that for exotic conifers in South Africa, monetary returns were likely to be derived from early thinning and spacing up to fifty per cent of the tree height. He stated that neither species or site quality influence the age at which mutual competition begins. Diameter increment was used as the main criterion to indicate the degree of competition. Johnston (1962), reporting on the recommendations of Craib (1947), found that 9 x 9 spacing for plantations was perhaps a maximum. He thought that these planting distances were not so remarkable when one considered that these exotic plantations attain a height of thirty-six feet in the first six years of growth. Disagreeing with Craib, he stated that no one thinning or planting regime can meet all the varying circumstances and conditions of a whole country.

Stephens, Spurr and Stephen (1948) showed that there was an immediate response to thinning by use of a dial dendrometer, and Smith (1958) found that coniferous wood of high quality can be grown faster with wider spacing. Staebler (1959) and Fedwick and Yoho (1960) illustrate the high cost of holding more growing stock than necessary to produce maximum yields. Buckman (1962), citing three density experiments in Minnesota, and many other thinning experiments, indicate that density over a fairly wide range has little effect on final yields. When the increased growth on merchantable trees is shown, thinning is usually justified. Buckman (1962) and others have shown that diameter growth on dominants and codominants was nearly doubled.

Deichman (1960) doubts from European experience that extremely fast growth rates can be maintained without deteriorating the soil. Light, early, frequent thinnings favor growth and insure even crown development and a minimum of snow breakage.

Fritts (1960), in his study of radial growth on individual trees - using multiple regression techniques - admits that the difficulty in analyzing single tree data is assessing the environment. He finds multiple regression techniques most satisfactory because allowance for the interaction of the various factors affecting growth may be given consideration. Temperature appears to be the most influential factor in control of growth. The optimum temperature range varies among species. Soil moisture is also limiting either when excessive (causing poor aeration), or when insufficient during prolonged rainless periods. He states that multiple regression techniques merely measure correlated variation and do not necessarily establish cause and effect relationships. To determine whether or not a factor is a truly casual one, the investigator must use his knowledge of the physiological processes involved.

Smith (1959) challenges conventional designs of thinning experiments: "Initial use of two rows of trees should be adequate and, even within these, we have some opportunity to use regression techniques to assess the influence of spacings within and between adjacent plots. It would be far cheaper and much more instructive to assess trends across plots than to create large surrounds. In all studies of spacing and thinning, very real advantages can be gained by the use of regression techniques, data for individual trees, and a relatively small final number of trees that is fixed after consideration of the requirements of the study."

While Smith does not specifically suggest a "clinal" plot arrangement as suggested by Pudden (Dawkins, H.C. 1960) where treatments are arranged systematically in serial order of intensity, and each treatment differs only slightly from its neighbor, this would be the case with the use of small surrounds. Scott (1962) contends: "The clinal plot layout... appears to offer considerable saving in experimental area by dispensing with plot surrounds. It is shown that this advantage is completely outweighed by the impossibility of any valid statistical analysis." One of the main objections is that, if site is variable, and usually it is even on relatively small areas of land, then variation due to site cannot be dealt with by randomization of treatment.

For future thinning and spacing experiments the author would suggest:

1. A randomized block layout, replicated.
2. A single-tree analysis. In addition, individual trees from point samples within the treated areas should be measured most carefully to determine if, from these samples, one can adequately predict growth of a stand.
3. Establishing experiments in young stands ten to twenty years old.
4. Treatments should be over a wide range of density, with special attention to low densities.
5. Measurements of soil nutrients, moisture, temperature, climatic variation and ecological succession should also be taken.

Growth is a complex phenomenon, not attributal to any one factor. The study of tree growth calls for the concentrated efforts of many specialists - in genetics, soils, tree physiology, ecology, as well as in mensuration.

COMPUTER PROGRAMS

Electronic computers and business machines offer many possibilities for the analysis of data that previously could not even be contemplated because of the tremendous amount of compilation required. With data processing equipment, it will not be necessary to have compilers for this purpose - except for checking of original data transcripts and the compilation of small problems that could not be economically done on machines. The rent for these machines remains fixed whether they are worked 8 hours a day or more. Information in the field would need to be obtained in a form suitable for machine compilation. The use of I.B.M.'s "port-a-punch" would be ideal for the recording of data on punch cards in the field, i.e. daily weather instrument readings.

Many computer programs for data processing are already available. Multiple regression techniques are now becoming quite popular and are useful for the analyses of many forestry problems. To cite a few, we have Grosenbaugh's (1958) "The elusive formula of best fit" giving the least squares formulae which predict Y using every possible linear combination of 9 or fewer variables. This program was developed for I.B.M.'s 704 computer. Godney, Martin and Johnson (1959) have developed "Specifications for calculating several equations of relationship between two variables on type 650 electronic computer". This type of program is most useful when the mathematical form of the relationship is unknown and several possible forms must be investigated. Mr. Harold Young of the University of Maine recently notified the author that the University of Maine computing centre has a multiple regression program for the I.B.M. 1620. It incorporates an innovation lacking in other programs: it is possible to make 13 different kinds of transformations such as multiplication, ratio, reciprocal, squares etc. The program can handle up to 35 variables or variations of variables. Dr. Harry Smith of the University of British Columbia has successfully used an Alwac III E computer for multiple regression analyses. This program gives the means, covariance matrix, standard deviations and correlation matrix, plus multiple regression analyses where the independent variables are eliminated in order of the most negative or least positive contribution to the explanation of the variance on Y.

Jeffers (1959) reports on the approach to multiple regression analyses of the British Forestry Commission which uses the services of the London computer centre on a Ferranti Pegasus computer. To give one some idea of the speed at which these machines work, a data tape with 12 variables and 200 sets of observation would be read off tape by the machine in five minutes. Two minutes is sufficient for the machine to calculate the equation with approximately 20 variables. The summary data from this program includes:

1. Mean, minimum and maximum, and standard deviation of each variable.

2. Correlation matrix between every pair of variables.

The output from the regression analyses with specified dependent and independent variables gives the sum of squares of the dependent variable followed by the regression constant and its standard error, and the partial regression coefficient and the standard error for each of the independent variables included in the equation. After the solution of each equation, the residual sum of squares is printed.

Mr. D.N. Brown, Computing Statistician, Statistical Research Service, of the Department of Forestry, Forest Entomology and Pathology Branch, has recently forwarded two I.B.M. 1620 programs for 1 dependent and up to 24 independent variables, and another program for 1 dependent and up to 6 independent variables. Both programs are essentially the same. The regression model is enlarged one variable at a time, until all independent variables are included. "The matrix of corrected sums of squares and cross products is reduced one step at a time, using the Gaus-Jordan reduction technique. At each step of the reduction, the regression coefficient for variables included, the residual sum of squares and contribution to the residual sum of squares by each variable not included are computed. The order of inclusion of the independent variables is specified by initial parameter cards".

While the foregoing is far from a complete list of programs possible for computers, it gives some idea of their capabilities.

EXPERIMENTAL DESIGN

Good experimental design can increase the precision of an experiment without unduly increasing the number of observations. This is well demonstrated in Fisher's (1960) famous tea cup experiment.

Ezekiel and Fox (1959), in the first few chapters of their book, show how meaningless correlations, though they may be sometimes high, are arrived at if the logic of the problem is not thoroughly understood.

The need for replication of experiments and healthy duplication of efforts is well put in a selected reference by Fisher (1960):

"I am very sorry, Pyrophilus, that to the many (elsewhere enumerated) difficulties which you meet with, and must therefore surmount, in the serious and effectual prosecution of experimental philosophy I must add one discouragement more, which will perhaps as much surprise as dishearten you; and it is, that besides you will find (as we elsewhere mention) many of the experiments published by authors, or related to you by the persons you converse with, false and unsuccessful (besides this, I say), you will meet with several observations and experiments which, though communicated for true by candid authors or undistrusted eyewitnesses, or perhaps recommended by your own experience, may, upon further trial, disappoint your expectations, either not all succeeding constantly, or at least varying much from what you expected."

Robert Boyle, 1673,
Concerning the Unsuccessfulness
of Experiments.

Fisher (1960) also points out that the design of experiments is, however, too large a subject and of too great importance "to the general body of scientific workers", for any incidental treatment to be adequate. "We need to study designs which have been widely successful in many fields, and to examine their structure in relation to the requirements of valid inference".

Reference books on experimental design and sampling techniques that should be purchased for our district office library are as follows:

1. Ezekiel and Fox (Third edition) (1959) Method of Correlation and Regression Analysis. John Wiley and Sons, Inc. New York, London. General Publishing Co. Ltd. 222 Adelaid St. W. Toronto.
2. Fisher, R.A. (Seventh edition) (1960). The design of Experiments. Oliver and Boyd Ltd. Edinburgh and London.
3. Fisher, R.A. (Latest edition?). Statistical Methods for Research Workers. Oliver and Boyd Ltd. Edinburgh and London.
4. Jeffers, J.N.R. 1960. Experimental design and analysis in forest research. Amgvist and Wiksell, Stockholm.
5. Schumacher, F.X., and R.A. Chapman. 1948. Sampling methods in Forestry and Range Management. Duke University. School of Forestry. Bulletin No. 7, Revised Edition.

Liaison with computer and statistical services in Ottawa should be maintained. In addition, group discussions at the district office level on the design and analysis of proposed experiments should be encouraged for the mutual benefit of all concerned. The method of solving different problems is much the same regardless of the problem.

INSTRUMENTATION

The development of improved instrumentation in forestry has been slow. Recently (1961), a forest mensuration committee of C.I.F. and S.A.F. members has been formed. This group will try to encourage development and testing of instruments. Instruments cited by Jameson (1962) for testing are as follows:

1. Bar and Stroud dendrometer for measuring height and diameter of standing trees. It also may be used as a rangefinder. The precision of measurements taken with the aid of this instrument in terms of standard deviation are: height ± 0.5 feet, diameter ± 0.3 inches and range ± 1.0 feet. Approximate price in Canada $1,065.00.
2. S-Lon Fibre Glass Tapes made from fibre glass, which, according to the manufacturer, are tougher than steel and more flexible. In addition, they are waterproof, non-conductive, accurate and graduations will not rub off. Price of 100' tape in Canada is approximately $11.00.

FOREST PRODUCT MEASUREMENTS

Considerable instrumentation for the measurement of pulpwood has been developed. Jameson (1962) reported on an electronic log scaler, where pulp logs are fed by a conveyor past a series of light sources in such a way that the mid-diameter of an 8-foot log is determined and its volume calculated and recorded on an adding machine.

A paper by Martin (1962), presented to the joint forestry field meeting of the American Pulpwood Association and the C.P.P.A. Woodlands Section, is most interesting from a forest mensuration point of view. A few stimulating comments from this paper are:

1. Wood measurement must be a "service" rather than a "control function". The view that wood is produced so that it may be measured is all too prevalent.
2. Measurement must be moulded to the operation; the operation cannot be altered to accommodate the requirements of measurement.
3. Rapid developments in harvesting techniques will change many conventional measurement requirements.
4. Government agencies usually draw up procedures on wood measurement. ..."The state is even less adaptable to change than people, and this has introduced an additional note of rigidity in measurement procedures"...
5. The conventional cord, cubic foot or F.B.M. measurements based on measurements at fixed lengths are simply not applicable after the wood is reduced into multiple sections of different lengths.
6. In a 4-foot pulpwood operation, 27 per cent of a man's time was spent with site preparation and piling specifically for measurement.

7. Electronic measuring devices of pulpwood are becoming popular in the east. Anon. (1962B).
8. In Canada, the use of cruise estimates for stumpage payments has been largely undeveloped.
9. The use of weight as a measure of pulpwood is still complicated by varying moisture content of the wood.
10. Significant opportunities for cost reduction as well as more precise measurement of raw material should offer sufficient motivation for more work in these fields.
11. Agencies supported by government and industry should be employed to solve these problems.

CONCLUSION

1. Volume tables - Nationally recognized volume tables and formulae should be prepared in Ottawa. District offices may carry out necessary application tests and develop methods for their application.
2. Sampling - Many fundamental facts concerning forest sampling are still to be determined, such as; the relative efficiency of plot and probability sampling; sampling design; and determining what sample distributions are involved with various techniques and strata.
3. Repeated Forest Inventories - This rapidly developing field is becoming increasingly important for national forest inventories, and for Management planning on specific areas. Many new concepts need further testing and some application for long term study.
4. Growth and Yield - Immediate emphasis on the prediction of growth for the purposes of forest management in Alberta appears to be out of perspective. Fundamental studies on growth should be undertaken to learn what parameters best define growth, and to correlate these to ecological factors which may be measured.
5. The design and analysis of experiments should be a continuing study.
6. The testing of instruments for measuring trees, sawlogs and pulpwood, etc., should be a part of forest mensuration.

PROGRAM

Two main divisions of forest mensurational study may be made:

1. Sampling techniques for forest inventory and management. Under this heading the following projects may be carried out:

    a. Determining appropriate angle gauge sizes, sampling designs and volume factors for point sampling of various strata.

    b. Studies on continuous or repeated forest inventory methods (Project K-37) and other new projects.

    c. The testing of volume sampling from air photographs. New project along the lines of project A-95.

    d. The development of double sampling with regression techniques for volume sampling using air photographs and ground samples. (New project).

    e. Development and testing of sampling methods for regeneration surveys. (New project).

    f. A study of sampling and compilation procedures of: height, age, diameter and form-class relationships on specified sites. Stem analysis techniques will be used. (New project. Project A-42 may be included.)

2. Studies of growth and yield.

    a. The study of growth and yield and relating it to ecological factors. Projects that are incorporated are: K-69, A-43, A-15, A-17, A-103. Co-operative studies with other research officers would be desirable.

b. Summarizing of thinning experiment results from K-3, K-56, K-57, and initiating K-76 to demonstrate soil moisture and temperature relations in treated areas.

The development of a successful forest mensurational program will be dependent upon:

1. Problems presented by industrial and government foresters of Alberta.
2. The establishment of a forest mensuration division in Ottawa to co-ordinate forest mensurational work at district levels.
3. The creation of an active forest mensuration committee in Alberta, perhaps under the auspices of the Rocky Mountain Section of the Canadian Institute of Forestry, is necessary for the communication of ideas among foresters interested in mensuration.
4. Trends in forest management and utilization that will take place in the future.
5. The assistance of fellow research officers and technicians. Ideally, one forest technician should be permanently assigned to forest mensurational work.

In addition to studies in Alberta, a certain amount of on-the-spot discussion with mensurationists elsewhere would be desirable:

1. To examine well designed experiments.
2. To see different utilization practices and determine what effect they may have on mensurational practices in Alberta.
3. To discuss methods and assess areas where forest inventory and management procedures have been successful.

4. To discuss compilation procedures and statistical analysis with specialists on computers and statistics.

Time for study and some additional course work on statistical analysis should be allowed for, so that this important mensurational tool remains in good repair.

Active Forest Mensurational Projects in Alberta

Project Number	Title
A-13	Density Indices for White Spruce.
A-15	Growth and Yield of Residual Stands of White Spruce in Logged Areas of the Boreal Forest Region of Alberta.
A-17	Yield of lodgepole pine in the Foothills section of the Boreal Region in Alberta. (R. F. Ackerman and P. J. B. Duffy).
A-42	Dominant height as a site index in low density lodgepole pine stands.
A-43	Growth and development of mature lodgepole pine stands under optimum conditions.
A-82	A demonstration of differences in productivity between physiographic groups of land conditions in the Foothills Section of Alberta. P. J. B. Duffy.
A-95	Standard aerial photo volume tables for lodgepole pine. P. J. B. Duffy and Alberta Forest Surveys Branch.
A-102	Point sampling and line plot cruising of merchantable timber stands in Alberta. C. L. Kirby.
A-103	Growth and yield of white spruce sawtimber following improvement cutting in 70-year-old spruce-aspen-pine stands, McKay, Alberta. C. L. Kirby.

K-37 Working plan survey of K.F.E.S.

K-3 Thinning of lodgepole pine.

K-56 Wholesale thinning of young lodgepole pine, mechanical, chemical and with fire.

K-57 The development of a 77 year old lodgepole pine stand following an empirical thinning.

K-60 Demonstration Area - Release Cutting.

K-63 Knot-free lodgepole pine by de-budding.

K-69 Density development in lodgepole pine stands in the subalpine region of Alberta.

REFERENCES

ANON. 1948. - Form-class volume tables. 2nd Edition. Dominion Forest Service, Ottawa.

ANON. 1959A. - Forestry handbook for British Columbia. The Forest Club, Univ. of B.C.

ANON. 1959B. - Specifications for permanent plots in forest management. Preliminary draft for the Lake States Council of Industrial Foresters. Lake States For. Expt. Stn.

ANON. 1962A. - Form-class volume tables for white spruce and lodgepole pine in Alberta. Alberta Dept. of Lands and Forests, Forest Surveys Branch, Alta.

ANON. 1962B. - Electronic Log Scaler. Lumberman 89(2).

ANON. 1962C. - Developing the data framework for effective timber management. Intermountain Forest and Range Experiment Station. U.S.D.A. Misc. Pub. No. 25.

BICKERSTAFF, A. 1947A. - One-fifth versus one-tenth acre plots in sampling immature stands. Silvicultural Res. Note No. 83. Dom. For. Br., Ottawa.

BICKERSTAFF, A. 1947B. - The measurement of growth on forest areas by means of recurrent line plot surveys. For. Chron. March 1947. Vol. 23(1).

BIOLLEY, H.E. 1920. - L'aménagment des forêts par la méthode expérimentale et specialement la méthode du contrôle. Attinger frères Neuchâtel et Paris. 90 pp.

BLYTH, A. W. 1952. - White spruce standard volume tables for the boreal and sub-alpine regions of Alberta. Dept. Res. and Development, For. Br. Silvicultural leaflet No. 60.

BLYTH, A. W. 1955. Standard Volume tables for lodgepole pine in Alberta. Dept. N.A. & N.R., For. Br., Tech. Note No. 9.

BRIEGLEB, P. A. 1950 . The use of yield tables in predicting growth, mortality and yield. In Timber management plans on the national forests by L.S. Gross. U.S.D.A. Washington.

BROWNE, J. E. 1962. Standard cubic-foot volume tables for the commercial tree species of British Columbia. B.C. For. Ser., Forest Surveys and Inventory Division.

BRUCE, D. and F. X. SCHUMACHER. 1934. Forest Mensuration. First Edition. McGraw-Hill Book Co., New York.

BUCKMAN, R. E. 1962. Three growing-stock density experiments in Minnesota Red Pine. Lake States For. Expt. Stn. Stn. Paper #99, U. S. D. A.

BRYAN, M. B. 1956. A simplified method of correcting for slope on circular plots. Jour. of For. Vol. 54(7).

CLARK, M. B. 1953. Relative efficiency of some specific plot sizes in estimating timber volume in some specific timber types. For. Chron. Vol. 29(3).

COCHRAN, W. G. 1959. Sampling techniques. John Wiley & Sons, Inc.

CRAIB, I. J. 1947. The silviculture of exotic conifers in South Africa. Jour. South African Forestry Assoc. No. 15.

CROSSLEY, D. I. 1959. Continuous forest inventory and its relation to forest management at Northwestern Pulp & Power Ltd. Canadian Pulp and Paper Association.

DAVIS, K. P. 1955. Points of appraisal concerning continuous forest inventory methods and objectives. Discussion at C.F.I. tour April 26, 1955 at Shawana, Wisconsin.

DAVIS, K. P. 1956. Determination of desirable growing stock - a central problem of forest management. Jour. of Forestry. Vol. 54.

DAVIS, K. P. 1958. Forest growth application, limitation and determination in management. Mimeographed outline of discussion presented to Lake States Council of Industrial Foresters Wausau, Wisconsin.

DAWKINS, H. C. 1960. The Pudden clinal plot; thinning experiments without surrounds. The Empire Forestry review. Vol. 29(2). No. 100.

DEICHMAN, V. V. 1960. Comments on economic models for thinning and reproducing even-aged stands. Jour. For. Vol. 58.

EZEKIEL, M. and K. A. FOX. 1959. Methods of correlation and regression analysis. John Wiley & Sons. 3rd Edition.

FEDWICK, J. and J. G. YO HO. 1960. Economic models for thinning and reproducing stands. Jour. For. Vol. 58(1).

FISHER, R.A. 1960. The design of experiments. Seventh Edition. Oliver and Boyd.

FRITTS, H. C. 1960. Multiple regression analysis of radial growth in individual trees. For. Sc. Vol. 6(4).

GEDNEY, N.R., D.E. MARTIN and F.A. JOHNSON. 1959. Specifications for calculating several equations of relationship between two variables on a type 650 electronic computer. Pac. N.W. For. & Range Expt. Stn. U.S.D.A.

GEVORKIANTZ, S.R. and L. P. OLSEN. 1955. Composite volume tables and their application in the Lake States. U.S.D.A. Technical Bulletin No. 1104.

GOLDING, D. L. 1960. - Master thesis: "Tests of precision of cubic-foot tree-volume equations on aspen, jackpine, and white spruce". Purdue University.

GOLDING, D. L. and O. F. HALL. 1961. - Tests of precision of cubic-foot tree-volume equations on aspen, jackpine and white spruce. For. Chron. Vol. 37(2).

GROSENBAUGH, L. R. 1955. - Better diagnosis and prescription in southern forest management. U.S.D.A. Occasional paper No. 145.

GROSENBAUGH, L. R. and W. S. STOVER. 1957. - Point-sampling compared with plot-sampling in southeast Texas. For. Sc. Vol. 3, No. 1.

GROSENBAUGH, L. R. 1958. - The elusive formula of best fit: a comprehensive new machine program. Southern For. Expt. Stn. Occasional paper No. 158.

HAGBERG, E. 1960. - Selecting objectives and methods of estimating forest resources. Paper presented to the Fifth World Forestry Congress, Seattle, Wash.

HALL, O. F. 1959. - The contribution of remeasured sample plots to the precision of growth estimates. Jour. For. Vol. 57(11).

HASEL, A. A. 1938. - Sampling error in timber surveys. Jour. Agric. Res. Vol. 57 pp. 713-716.

HASEL, A. A. 1950. - Inventories for management plans. In timber management plans on the national forests. Edited by L. S. Gross. 1950. U.S.D.A.

HONER, T. G. and L. SAYN-WITTGENSTEIN. 1962. - Report of the committee on forest mensuration problems. Mimeo.report. 18 pp.

ILVESSALO, Y. 1932.- Some main characteristics of permanent sample plot work in Finland. International union of forest research organizations. Proceedings of the 8th Congress, Nancy.

JAMESON, J. S. 1962. Memorandum to the forest mensuration group. Mimeo. 2 pp.

JEFFERS, J.N.R. 1959. Multiple regression analyses by electronic computers. The Empire Forestry Review. Vol. 38(3). No. 97.

JOHNSON, F.A. and H. J. HIXON. 1952. The most efficient size and shape of plots to use for cruising in old-growth Douglas-fir timber. Journal of Forestry, Vol. 50(1).

JOHNSTON, B.A. 1962. Growing conifers in South Africa. The Empire Forestry Review. Vol. 39(2). No. 100.

KEMP, P. D. 1957A. Regression coefficients for computing cubic-foot volume of Rocky Mountain trees. Research Paper No. 40. U.S.D.A.

KEMP, P. D. 1957B. A procedure for converting conventional tree volume tables to formulae (Part 1). Research Paper No. 43. U.S.D.A.

KER, J. W. 1962. The theory and practice of estimating the cubic content of logs. Forestry Chronicle. Vol. 38(2).

KIRBY, C. L. 1960. A taper and volume table and volume formulae for black spruce in Saskatchewan. Vol. 36(3).

KIRBY, C. L. 1961. Point sampling. Masters Thesis. Univ. of Michigan .

KNUCHEL, H. 1953. Planning and control in the managed forest. Translated by M.L. Anderson. Oliver and Boyd.

KOZLOWSKI, T. T. 1962. Tree Growth. Ronald Press Co., N. Y.

MARTIN, W. H. 1962. Trends and developments in wood measurement. Paper prepared for joint meeting of American Pulpwood Assoc. and C.P.P.A, Newton Falls, New York. Mimeo. 5 pp.

MESAVAGE, C. and L. R. GROSENBAUGH 1956. Efficiency of several cruising designs on small tracts in North Arkansas. Jour. of Forestry. Vol. 54(9).

MEYER, H. A. 1949. Cruising intensity and accuracy of cruise. Jour. of Forestry. Vol. 47(8).

MEYER, W. H. 1953. The periodic inventory on forest management. Jour. of Forestry. Vol. 51(4).

MEYER, W. H. 1960. Impressions of industrial forestry in southeastern United States. Jour. of Forestry. Vol. 58(3).

MORRIS , D. J. 1962. Trends in timber management planning on the national forests. Jour. of Forestry. Vol. 60(5).

PALLEY, M. N. and L. G. HORWITZ. 1961. Properties of some random and systematic point sampling estimators. For. Science Vol. 8(1).

ROCKY MOUNTAIN SECTION, C.I.F. 1961. Papers presented on Jan. 11, 1961 meeting. Mimeo.

SCHUMACHER, F. X. and F.D.S. HALL. 1933. Logarithmic expression of timber-tree volume. Jour. of Agric. Res. Vol. 47, pp. 719-734.

SCHUMACHER, F. X. and R. A. CHAPMAN. 1948. Sampling methods in forestry and range management. Duke University School of Forestry. Bull. No. 7, Revised Edition.

SCOTT, J. F. 1962. Statistical objections to the clinal plots. Empire Forestry Review. Vol. 41(1).

SEELEY, H. E. 1961. Some investigations of forest sampling methods. Canada Dept. of Forestry. Tech. Note No. 111.

SHIUE, C. J. 1960. Systematic sampling with multiple random starts. Forest Science. Vol. 6(1).

SHIUE, C. J. and H. H. JOHN. 1962. A proposed sampling design for extensive forest inventory: Double sampling for regression with multiple random starts. Jour. of Forestry. Vol. 60(9).

SMITH, J.H.G. and J.W. KER. 1957A. Timber volume depends on D^2H. B. C. Lumberman. Sept., 1957.

SMITH, J.H.G. and J. W. KER. 1957B. Some distributions encountered in sampling forest stands. Forest Science. Vol. 3(2).

SMITH, J.H.G. 1958. Better yield through wider spacing. Journal of Forestry. Vol. 56(7).

SMITH, J.H.G. 1959. Comprehensive and economical designs for studies of spacing and thinning. Forest Science Vol. 5(3).

SPURR, S.H. 1952. Forest inventory. The Ronald Press Co.

STAEBLER, G.R. 1959. Optimum levels of growing stock for managed stands. Proceedings Society of American Foresters. 1959.

STOTT, C.B. and E.J. RYAN. 1939. A permanent sample plot technique adapted to commercial timber stands. Journal of Forestry. Vol. 37, pp. 347-349.

STOTT, C.B. 1947. Permanent growth and mortality plots in half the time. Journal of Forestry. Vol. 45, pp. 669-673.

WARE, K.D. and T. CUNIA. 1962. Continuous forest inventory with partial replacement of samples. Forest Science. Mono. No. 3.

YOUNG, H.E. 1961. Report of forest mensuration group. Journal of Forestry. Vol. 37(4).