SAMPLING A STAND IN FOREST SURVEY

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Foreword

This paper is concerned with investigations into forest survey methods made at the Institute of Forest Mensuration and Management, University of Helsinki, within recent years. The project has for the most part been financed with the aid of a grant made by the United States Department of Agriculture, Agricultural Research Service.

The authors have been in close cooperation during the project. NYYSSÖNEN, the senior author, is mainly responsible for the overall planning of the work, discussion of the results and writing the report, while field and office work, including the programming of the computations, has largely been in the hands of KILKKI, the junior author.

The authors wish to express their thanks for the help given, the comments made and the interest shown by a number of persons, including authorities of U.S. Forest Service.

Contents

1. Introduction

The purpose of this paper is that of reporting tests made on the basis of Finnish material with regard to the efficiency of the 10-point cluster in sampling a stand in forest inventory. Currently, this system is applied in field work of the national forest survey in the United States of America (Forest survey . . . 1963). The pattern results in 10 equilateral triangles with sides of 66 feet (about 20 metres) in length between the points (Fig. 1). Substitute points are taken in accordance with definite rules in the event that any of the points falls on non-commercial forest or non-forested land.

At each point on a variable (relascope) plot, data are recorded in respect of all live trees of 3.0 inches or more d.b.h. that fall within the limiting distance of the basal area factor designated for the area. For instance, in the east, each tree counted represents 37.5 sq.ft./acre (8.6 sq.m./ha.). Smaller trees, seedlings, dead trees, and stumps are recorded on given fixed plots around each point.

To understand the background of application of the above method, it must be remembered that the chief function of the forest survey is to provide guides for the formulation of forestry programmes and policy at both local and national levels. The task involves the estimation of timber volume and growth by species, size, etc.; but it is also necessary to know the relationships which exist between growth and area conditions, especially those conditions such as density, spacing, structure, composition and tree quality, which are modifiable through management action.

Sampling and various measurements have long been used for obtaining information on volume and growth. Nevertheless, stand condition and treatment needs have so far been estimated mainly by ocular means; this has, for instance, been the case in national forest surveys in the Scandinavian countries Finland, Norway and Sweden, where so-called cutting classes (or stand development classes) have been introduced for the purpose. In the United States, however, systems requiring more detailed observations

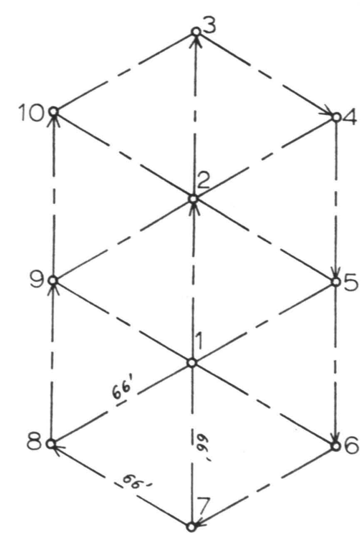

Fig. 1. Ten-point cluster diagram.

have been developed in recent years. A special survey for calculation of »productivity index» on recently cut lands was made in 1952 (Timber resource . . . 1955). At present, area condition classes are used; these refer to the condition of commercial forest land with respect to current and prospective productivity (Forest survey . . . 1963; HASEL and LARSON 1959).

For the estimation of both inventory volume and area condition, the minimum area to be classified needs to be considered from different aspects. The area should be sufficiently large enough to permit of the application of aerial volume tables in double sampling. Against this, a relatively small minimum often diminishes the disagreement between photo and field classifications. It is also necessary to think of what is the most realistic unit of area for intensive management. In the consideration of these and other aspects of the national forest survey of the United States, a one acre area was selected, which »lends itself better, perhaps, to reporting results by cumulative tables or curves, because the acre is the unit size commonly used in reporting» (HASEL and LARSON 1959).

Following this decision, there arises the question of the way in which an acre should be sampled to arrive most efficiently at results, firstly with respect to volume and growth, and secondly, area condition classification. On the foundation of various tests (cf. Office report . . . 1960) the 10-point cluster explained on p. 1 was introduced.

When the 10-point cluster is compared with a number of other designs in this paper, the principal results are concerned with the ability of different designs to provide gross volume estimates. As a measure of efficiency, use is made of the total variance corrected with the time factor.

2. Test procedure

21. Designs compared

The 10-point cluster was tested, and compared with 13 other designs. These consisted of both variable (relascope) plots with different basal area factors (BAF), and circular plots of different sizes. The different designs are listed below.

No. 1. One variable plot BAF 1 (in metric system, equals BAF 4.356 sq.ft./acre).
» 2. » circular » 1 250 sq.m.
» 3. » » » 1 000 »
» 4. » » » 500 »

» 5. Two variable plots BAF 2
» 6. » circular » 625 sq.m. each
» 7. » » » 500 » »
» 8. » » » 250 » »

» 9. Four variable plots BAF 4
» 10. » circular » 312.5 sq.m. each
» 11. » » » 250 » »
» 12. » » » 125 » »

» 13. Ten variable plots BAF 10 (10-point cluster)
» 14. Complete enumeration of all the trees on 0.4 hectares.

The plot centres are 40 metres apart in Designs 5 to 8, in the corners of a rectangle of 20 by 40 metres in Designs 9 to 12, while in the 10-point cluster (cf. Fig. 1, p. 5) the sides of equilateral triangles are 20 metres.

In the tables presented later, the results for different designs are given in the following format:

1	5	9	13
2	6	10	
3	7	11	14
4	8	12	

22. Measurements made in test stands

Table 1 presents some of the basic characteristics of 12 stands measured in State forests in the southern half of Finland, plots No. 1 to 6 being in the Evo district 25°10′ E. long. and 61°15′ N. lat., and plots No. 7 to 12 in the Nikkarila district 27°40′ E. long. and 62°25′ N. lat. In general, the test stands are stands in the preparation stage, or mature stands to be regenerated (stand development classes 3 and 4). As a rule, the main tree species are Scotch pine and Norway spruce. The arithmetical averages per hectare are: stem number 585, basal area 21.6 sq. metres, and gross volume 224 cu.m.

From each stand there was selected an area of 0.4 hectare (80 times 50 metres) or about one acre. The two coordinates of each tree were measured to an accuracy of 0.1 metres (thus, one from 000 to 800, the other from 000 to 500) and registered on a mark-sense card with other data. On the basis of the tree species, d.b.h., height, and taper, the stem volume could be taken from Ilvessalo's (1947) tree volume tables. The tree quality was recorded in accordance with following classes:

1. desirable; in general a dominant tree with a good stem,
2. acceptable; in most cases a co-dominant tree, with stem at least satisfactory, and
3. inferior; tree to be removed in thinning.

Table 1. Characteristics of the test stands.

Stand No.	Forest site type	Main tree species	Age class, years	Mean diam., cm.	Mean height, m.	Number of stems per ha.	Basal area, sq.m./ha.	Volume, cu.m./ha.
1	VT	Pine	115	24.0	19.3	338	14.3	140
2	MT	Pine + Spruce	75	27.5	22.6	455	20.0	208
3	OMT	Pine + Spruce	105	29.8	24.3	452	25.7	299
4	MT	Pine + Spruce	105	27.1	23.6	1 360	37.6	393
5	VT	Pine	125	28.1	23.3	352	20.0	228
6	MT	Spruce + Pine	95	33.1	24.9	465	27.9	324
7	VT	Pine	95	21.2	15.8	410	10.2	81
8	MT	Spruce	115	23.3	20.2	420	16.1	165
9	MT	Pine + Spruce	95	22.9	19.8	518	17.4	176
10	OMT	Spruce	115	25.8	20.0	840	29.6	297
11	VT	Pine + Spruce	95	19.8	17.6	910	22.9	204
12	MT	Spruce + Birch	95	23.4	20.1	502	18.1	172

In addition, there was registered with respect to each tree the number of saw logs of about 18 feet in length with a grade of the first saw log.

Further, some time studies were made in test stands, as all the time data necessary in this study were not available from a more comprehensive investigation conducted by this institute. First of all, the times needed in application of the 10-point cluster were recorded by measurement of this cluster 4 times in seven stands, which resulted in 28 cases of tree tally and defining plot perimeter. Second, 8 variable plots of both BAF 1 and BAF 4 were studied in seven stands, which resulted in 56 cases of both plot types. The crew consisted of a leader and two or three assistants.

23. Computations

The total variance, comprising the variance within stands and the variance between stands was chosen for comparison of the ability of different designs to provide satisfactory estimates of volume. This was considered to be comparable with common practice in determination of the total volume (cf. Office report . . . 1960). Volume plots are often grouped by area strata and average volumes per unit area, total volume and sampling errors determined for the strata. The sampling errors arrived at, along with the variation coefficients used for estimation of the sample size are based on the variance within the strata.

Time data were used as a cost factor to weight the variances of the estimates from each design, to provide a means of evaluating the relative efficiency of different designs.

Computation procedure will be described separately for variation and time studies. In various calculations, an IBM 1620 computer was used.

231. Variation

For calculation of the variances within stands in the different designs, each of the 13 designs (complete tally excluded) was applied 5 times on each stand. The plots were located systematically in an area within the mapped stand which was as large as possible. For example, the plot centres were located for Designs 1 to 4 as follows (the coordinate in the direction of the longer side is stated first): 200, 300; 300, 200; 400, 300; 500, 200; 600, 300. In a 10-point cluster the counting points are at 1 metre distance in the direction of the longer side.

The differences between the volumes obtained in the way explained above and the true volumes (per hectare) were calculated in each of 12 stands; this resulted in 60 differences for each design. These differences squared and divided by 59 gave the results which represent the variance within stands in Table 2. The table format on page 7 indicates the place of each design.

Table 2. Variances within stands for gross volume on different designs (cu.m./ha.).

1 671	1 043	1 043	736
753	607	522	
895	741	750	0
1 698	1 537	1 382	

To make some comparative material available, the results of rectangular plots can be presented. Each test stand was divided into 64 rectangles of 62.5 sq.m. (10 m. times 6.25 m.). By combination the neighbouring rectangles, calculations could also be made for larger plots. The variances within stands for each plot size were calculated by dividing the squared differences between plot and stand volumes by the plot number. The following set-up shows the average variance for different plot sizes:

Plot size, sq.m.	Variance, cu.m./ha.
62.5	18 579
125	7 635
250	3 748
500	1 671
1 000	940
2 000	361

Variances for the 500 and 1 000 sq.m. plots given above and in Table 2 are the only ones capable of immediate comparison. These variances are relatively close to each other: for 500 sq.m. plots 1 671 taken against 1 698, and for 1 000 sq.m. plots 940 against 895.

In addition to sampling studies, variances of the set-up and Table 2 may be of value, for instance in the design of thinning experiments. In consideration of the plot size and number of replications, the coefficients of variation calculable from the set-up may be of great help. Further, the effect of systematic location of plots can be brought into the picture by comparison of the two series of numbers. For instance, on division by 4 of the variance of 125 sq.m. plots in the set-up, 7 635, 1 909 is obtained, while the variance of Design 12 (four 125 sq.m. plots 20 m. times 40 m. apart) is 1 382.

To make possible a comparison of the variances of the volume of saw-timber trees with those of gross volume (Table 2), Table 3 was calculated. From a relative point of view, 10-point cluster and variable plots in the latter table seem in

Table 3. Variances within stands for volume of saw-timber trees on different designs (cu.m./ha.).

1 585	1 001	1 010	656
908	593	610	
1 080	674	896	0
1 786	1 707	1 352	

general to have a variance which is slightly less than that of fixed area plots. As a whole, however, there is not much deviation from the picture derived from gross volume in this stand material, where the mean for saw-timber trees is 182 cu.m./ha., and that for gross volume 224 cu.m./ha.

To revert to calculation of the total variances for gross volume in the different designs, the variances between stands must be added to the »within» variances of Table 2. The coefficient of variation of stand volumes was 40 per cent in the test material (cf. Table 1, p. 8). Since the stands were selected subjectively, this figure need not be representative. Nevertheless, this kind of variation has also been found in other Finnish material. Thus there may be added to the variances of Table 2 the »between» variance 8 028, corresponding to the 40 per cent coefficient of variation, and, for illustration of the effect of more extreme cases, also variances 2 007 and 18 063, representing 20 and 60 per cent variation, respectively.

The total variances indicate the relative number of sampling units needed for a stated accuracy in different designs and in three alternatives of »between» variation. In a way, the supposed forest areas consist of 0.4 hectare stands which are sampled by means of 14 designs.

232. Time

The relative time necessary for different designs has been calculated in two parts: first, the time required by tree tally (registration of d.b.h.) and defining plot perimeters, and secondly, the time spent in other phases of inventory work.

Two functions which give the joint time in minutes (Y) for defining plot perimeter and for tree tally had been calculated in a more extensive study. Function (1) is for circular plots of 100 to 1 000 sq.m.:

$$Y = 0.152\ X_1^{\ 0.741}\ X_2^{\ 0.279} \qquad (1)$$

where X_1 = stem number per plot + 1,
X_2 = plot size in 100 sq.m.

Function (2) had been calculated for variable plots of BAF 1 and 2:

$$Y = 0.470 + 0.106\ X_1 + 0.478\ X_2 \qquad (2)$$

where X_1 = stem number per plot,
X_2 = number of borderline trees checked with caliper and measuring tape.

In addition, it could be decided from measurements made on square plots that the same task in a 0.4 hectare stand, with a stem number of 600 trees/ha., required 30 minutes.

On the basis of new time data (cf. p. 9), function (3) was calculated for variable plots of BAF 4:

$$Y = 0.159 + 0.0949\ X_1 + 0.388\ X_2 \qquad (3)$$

where X_1 and X_2 have the same meaning as in function (2). It may be mentioned that the coefficient of correlation, R, equals 0.89, the standard deviation from the mean is 0.445, and the standard error of estimate is 0.208.

Function (4) was calculated for a 10-point cluster:

$$Y = 7.730 + 0.168\ X_1 + 0.554\ X_2 \qquad (4)$$

where X_1 = stem number per cluster,
X_2 = number of borderline trees per cluster, checked with caliper and measuring tape.

The standard deviation from the mean is 1.96, and the standard error of estimate 1.13, the value of R being 0.83. Functions (3) and (4) have been transformed to the level of Functions (1) and (2) by the multiplier 0.981, derived from repeated measurements of variable BAF 1 plots.

The additional figures needed for each sampling unit, to enable calculation of the time required for defining plot perimeters and tree tally, comprise the time taken in measuring and moving between the plots in 2 and 4 plot systems, and the number of borderline trees checked with caliper and measuring tape on variable plots. The average time between plots was 0.0476 minutes/metre. The number of borderline trees assumed as being checked in different cases was:

BAF	1	4 trees per sampling unit
»	2	3 » » » »
»	4	2 » » » »
»	10	2 » » » »

With a large BAF, it has not been considered necessary to check as many trees as with a smaller BAF. One tree represents about 5 per cent of the total number of trees counted.

Table 4 gives the times in minutes per sampling unit (e.g. 10-point cluster) for defining plot perimeters and tree tally. On the basis of comparisons made between these times, and corresponding times in an inventory made by a timber

Table 4. Times for defining plot perimeters and tree tally (in minutes per sampling unit).

4.70	8.49	9.19	12.50
7.31	11.09	13.11	
5.86	9.65	11.63	30.00
2.92	6.77	8.95	

company in practice, it is to be noticed that the former figures (Table 4) need to be multiplied by 3 at least in order to arrive at the latter times.

Secondly, discussion is necessary as regards the time requirements for other inventory work, such as sample tree measurements (height, taper etc.) and going to and from a sampling unit.

The time taken for sample tree measurements and other observations depends mainly upon the number of sample trees. D.b.h. measurements (tree tally) relate to varying stem numbers in different designs, as is observable from the following average figures: 22 trees in Designs 1, 5, 9 and 13; 73 trees in Designs 2, 6 and 10; 58 trees in Designs 3, 7 and 11; 29 trees in Designs 4, 8 and 12; and 234 trees in Design 14. Irrespective of these varying numbers of trees tallied, it can be assumed that without the loss of too much of the comparability, the same number of sample trees (about 20 for instance) is measured when using any design. Consequently, it is supposed that an equivalent period of time is necessary for sample tree measurements.

The time taken in movement to and from a sampling unit, including location, varies in accordance with several factors: accuracy requirements, the variance of a design, forest area, density of roads, etc. Under given conditions, the time between sampling units may depend on the variance of the design in question. If the variance is large, more plots and somewhat less time per plot are needed than is the case with a smaller variance.

For lack of detailed time studies, an additional time for sample trees, and for travelling between sampling units, was calculated in accordance with three possibilities: about 30, 60, and 120 minutes. On each design, a correction was made of one third of these times, i.e. 10, 20 or 40 minutes, respectively, with a multiplier inversely proportional to the square root of the ratio of the designs variance and mean variance; this was done so that due need could be paid to the differences in travelling time referred to above. In the light of the fact mentioned earlier that, say, a 3-fold multiplier may be necessary for transformation of the relative times used in this study to the level applicable in practice, the additions from 30 to 120 minutes seem to cover the range to an adequate extent.

Finally, relative times were calculated on the basis of the total variances and the total times for 9 series, each of them including 14 designs. Table 5 gives an example of one series of relative times.

Table 5. An example of the relative times on different designs. Variance between stands 8 028, average time added 60 minutes.

1.029	1.099	1.111	1.170
1.087	1.148	1.183	
1.061	1.124	1.156	1.464
1.000	1.062	1.101	

3. Discussion of the results

Nine series of adjusted variances were calculated by multiplying each of the three alternatives of total variances by three different alternatives of relative times, as discussed in the previous chapter. After giving the value 1 000 to the smallest variance in each series, these adjusted relative variances have been included in Table 6. Each series takes the form of table format used throughout the paper. In addition, a cluster of figures for each design in Table 7 gives the efficiency order of 14 designs in different alternatives of variation and time.

Table 6. Adjusted relative variances.

Variation	Time A	Time B	Time C
	Variance		
	1 191 1 125 1 146 1 133	1 227 1 108 1 120 1 072	1 395 1 227 1 234 1 159
I	1 000 1 050 1 069	1 000 1 008 1 007	1 118 1 100 1 086
	1 007 1 056 1 113 1 199	1 024 1 029 1 061 1 007	1 155 1 132 1 154 1 000
	1 137 1 226 1 218	1 201 1 230 1 186	1 384 1 376 1 305
	1 052 1 102 1 121 1 180	1 054 1 053 1 065 1 083	1 065 1 036 1 042 1 037
II	1 038 1 125 1 170	1 008 1 047 1 068	1 000 1 012 1 021
	1 013 1 101 1 157 1 534	1 000 1 041 1 072 1 241	1 002 1 016 1 033 1 087
	1 000 1 100 1 143	1 027 1 073 1 105	1 052 1 068 1 072
	1 055 1 139 1 160 1 240	1 027 1 060 1 070 1 106	1 025 1 028 1 034 1 046
III	1 089 1 191 1 243	1 028 1 078 1 103	1 007 1 037 1 039
	1 053 1 156 1 215 1 686	1 011 1 063 1 094 1 325	1 000 1 024 1 040 1 144
	1 000 1 114 1 171	1 000 1 057 1 083	1 011 1 038 1 048

E x p l a n a t i o n s

Variation I: 20 per cent, » II: 40 » », » III: 60 » » — coefficient of variation between stands; the corresponding variances added to the variance of each design within stands.

Time A: 30 minutes, » B: 60 », » C: 120 » — added as a time of sample tree measurement and that of travelling between sampling units to the basic time of each design for tree tally and defining plot perimeters.

Table 7. Order of efficiency of 14 designs in different alternatives.

Variation	A	B	C	A	B	C	A	B	C	A	B	C
	Rating											
I	11	13	14	7	9	9	10	10	10	8	8	8
II	4	7	11	7	6	7	8	8	9	13	12	8
III	3	3	5	6	6	6	8	8	7	12	13	12
I	1	1	4	3	4	3	5	2	2			
II	3	2	1	9	5	3	12	9	5			
III	4	4	2	10	9	8	13	12	10			
I	2	5	7	4	6	5	6	7	6	12	3	1
II	2	1	2	6	4	4	11	10	6	14	14	14
III	2	2	1	7	7	4	11	11	11	14	14	14
I	9	12	13	14	14	12	13	11	11			
II	1	3	10	5	11	12	10	13	13			
III	1	1	3	5	5	9	9	10	13			

E x p l a n a t i o n s

Table format, cf. p. 7.

Variation I: 20 per cent, » II: 40 » », » III: 60 » » — coefficient of variation between stands; the corresponding variances added to the variance of each design within stands.

Time A: 30 minutes, » B: 60 », » C: 120 » — added as a time of sample tree measurement and that of travelling between sampling units to the basic time of each design for tree tally and defining plot perimeters.

The sums of the ordinal numbers of each design in Table 7 enable grouping of the compared designs as follows.

Designs 2 and 3 (one circular plot of 1 000 or 1 250 sq.m.) are the most efficient.

The second group is formed by Designs 4, 6 and 7 (one circular plot of 500 sq.m. and two circular plots of 500 or 625 sq.m. each).

The third group comprises Designs 1, 5, 9, 10 and 11 (the following variable plots: one BAF 1, two BAF 2 and four BAF 4, and four circular plots of 250 or 312.5 sq.m.).

Designs 8 and 13 (two circular plots of 250 sq.m., and ten variable plots of BAF 10, i.e. *a 10-point cluster*) belong to the fourth group.

Designs 12 and 14 (four circular plots of 125 sq. m. and complete tally) were found least efficient in this test.

Attention can be drawn to some trends in Tables 6 and 7, where the variation grows from the top downwards, and the time from left to right.

With increase in the time between sampling units (for instance with lower requirements for accuracy), the designs with small »within» variance (e.g. No. 6 and 10; cf. Table 2 p. 10) become more efficient.

If the variance between stands is relatively small, those designs with a small »within» variance can be used to more advantage (No. 2, 3, 6, 7, 10, 11); even a complete tally may be the most efficient method if the time between sampling units is long (large area, accuracy requirements low etc.). Also, 10-point sampling is a rather efficient method in a case of small »between» variance. All this is in conformity with an earlier finding (STRAND 1957; cf. NYYSSÖNEN and VUOKILA 1963): the more homogeneous the material, and the more detailed the stratification, the larger should the sample plots be.

If large variation exists between stands, single plots, measured rapidly, seem to give the best results.

The designs in which variable (relascope) plots were used fall in general within the third group as regards efficiency, on the assumption that a reasonable number of borderline trees is checked with a caliper and measuring tape. Another assumption in the comparison of different designs, that equal time is spent on sample tree measurements, may have favoured fixed radius plots somewhat, and, especially, a complete tally: the efficient selection of sample trees constitutes one of the strong points of variable plots. Moreover, in stands less homogeneous than the test material, the relascope might more successfully preclude the tallying »unnecessary» trees than does the use of fixed radius plots.

Finally, as regards the principal comparative design, the 10-point cluster, it may briefly be stated that for inventory volume this design has on the average been about 10 per cent less efficient than the best design of different alternatives.

In this connection, however, there must be remembered the twofold task of forest survey, discussed in the introduction. In addition to volume and growth, area condition classes also need to be surveyed. Since these currently include estimation of the distribution of trees in a stand, the 10-point cluster may be the only one of the designs tested for volume which is capable of providing information on condition classes (cf. Office report . . . 1960).

It can now be assumed that the 10-point cluster is used for area condition classification, and in each alternative the most efficient design of the above comparison for volume. In this case, the time for a tree tally in the 10-point cluster, 12.5 minutes, was added to the time required by the most efficient design. However, the use of the 10-point cluster in this way for both purposes was about 10 per cent more efficient than the combined use of one design for volume, and another for area condition.

When area condition classes are determined by means of the 10-point cluster, there can be counted the proportion of stocking in desirable trees. The stocking

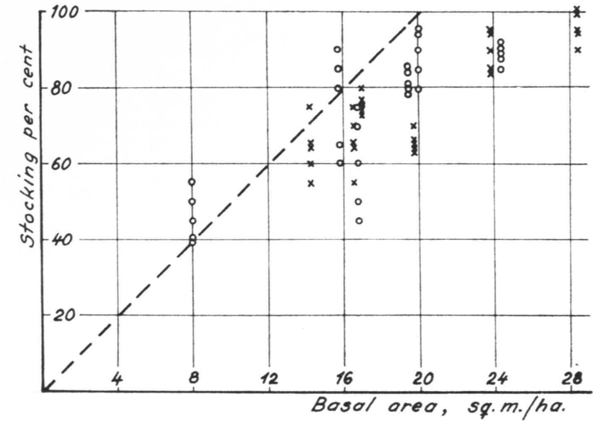

Fig. 2. Desirable and acceptable trees: stocking percent as a function of basal area. Five counts in each stand with 10-point cluster, BAF 10 and 2-tree expectancy per point.

goal in a basal area, and the number of trees expected per point, determine the BAF to be applied. Thus, if the goal is 20 sq.m./ha., and two trees are expected per point, BAF 10 will be used. One tree adds 5 per cent to the stocking percentage. As a rule, all the trees in excess of the required number at a point are tallied, but disregarded in calculation of the stocking percentage.

Although the purpose here is not that of more thorough discussion of the estimation of area condition, the stocking percentages of desirable and acceptable trees derived from 5 counts in test stands are shown in Fig. 2, with a view to providing some idea of the method. The average basal area of these trees is 18.6 sq.m./ha. and the mean volume 199 cu.m./ha.; the corresponding values for the whole stock are 21.6 and 224. Fig. 2 indicates that the smallest range in counting the stocking was 5 percentage units in 4 stands, and the widest range 30 units in 2 stands.

4. Summary and conclusions

This paper reports on tests, made on the basis of Finnish material, for comparison of the 10-point cluster of variable plots with 13 other designs in sampling a stand in forest survey. The research material consists of 12 stands, with Scotch pine and Norway spruce the main species. The mean volume is 224 cu.m./ha., the stand age varies from 75 to 125 years, and the mean diameter from 19.8 to 33.1 cm. By mapping the location of each tree with the measurement of the two coordinates on an area of 0.4 hectares, the variation, using different designs, could be studied with the help of an electronic computer.

The main results are concerned with the ability of different designs to provide gross volume estimates. As a measure of efficiency, three alternative series of variances were used, adjusted by three alternatives of time. The results are applicable, for instance, in double-sampling with photo and field classifications. In the comparisons, no attention has been paid to the possibility of systematic errors in various designs.

For inventory volume, the 10-point cluster proved to be about 10 per cent less efficient than the best design of each alternative. The use of a single circular plot of 1 000 sq.m. can be recommended under the conditions of this test; furthermore, one or two 500 sq.m. plots were more efficient than any combination of variable plots.

The reason for the use of the 10-point cluster in forest surveying has been the ability of the design to provide simultaneous information on area condition classes. Among the designs tested here, the 10-point cluster seems to be the only one capable of application in the estimation of condition classes, including distribution of the trees in an area. Calculations made on time-spending seem to indicate that the use of the 10-point cluster for both volume and area condition gives more efficient results than does the combined use of the most efficient design in each alternative for volume and 10-point cluster for area condition.

A more complete evaluation of the estimating area condition classes has not been effected in this context. Most of the information obtained by means of the 10-point cluster can be gained through ocular estimation, and from the sample trees to be measured in any design, but a cluster of several points appears to offer a good means of estimation, for instance, of the presence of clumps and gaps in a stand. On the other hand, as regards growth and stand development in

general, the difference in the homogeneity of tree distribution have so far not been considered an essential factor in managed forests, at least as far as Scandinavian forests are concerned. The problem is one which calls for further study.

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