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Studies on improvement of the efficiency of systematic sampling in forest inventory

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and Pekka Kilkki

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STUDIES ON IMPROVEMENT OF THE EFFICIENCY OF SYSTEMATIC SAMPLING IN FOREST INVENTORY

SYSTEMAATTISEEN OTANTAAN PERUSTUVAN METSÄN INVENTOINNIN TEHOKKUUDESTA

AARNE NYYSSÖNEN, PENTTI ROIKO-JOKELA
and PEKKA KILKKI

HELSINKI 1971

Suomalaisen Kirjallisuuden Kirjapaino Oy Helsinki 1971

PREFACE

The authors of this paper are grateful to many persons who have in different ways been engaged in this study, which is based upon rather extensive field and computation work carried out during the course of a number of years. The National Research Council for Agriculture and Forestry provided financial support for the work in the years 1966—1968.

In regard to the authors, ROIKO-JOKELA attended to the bulk of the computation required, while KILKKI put a great deal of effort into regression analysis and efficiency calculations. NYYSSÖNEN was in charge of the work in the planning, field work and analysis stages, and wrote the manuscript. Discussion between the authors was an essential factor in giving form to this paper.

Helsinki, January 1971.

CONTENTS

1. INTRODUCTION

This paper represents a continuation of an earlier study made in the Department of Forest Mensuration and Management, University of Helsinki (NYYSSÖNEN, KILKKI and MIKKOLA 1967). That study gave growing stock variation data based upon four test areas in Finland, and one in Mexico, along with comparisons drawn between different sampling methods. Further, the problem of estimation of the precision in systematic sampling was discussed, and in conclusion regression equations were presented for the determination of sample size.

Since the main results of the above study were based on one test area only, it was considered necessary that additional material be measured to permit of the estimation of sample sizes in a way which would be more generally applicable. Simultaneously, it seemed helpful to embark upon a more detailed study of, for instance, those combinations of fixed-area plots in which large trees are tallied upon a larger area than are small ones. However, the main reason for continued studies was the aim of evaluating the relative efficiency of different alternatives. Consequently, attention had to be paid to inventory costs arrived at by the analysis of time studies; earlier, publication has been limited to some preliminary results in respect of efficiency (cf. NYYSSÖNEN 1966).

2. SAMPLE SIZE CALCULATIONS

21. Test materials

The principal test area, Evo (Area 1), described in the paper by NYYSSÖNEN, KILKKI and MIKKOLA (1967), and comprising 100 hectares of land, is also one of the two areas analyzed in the present study. Another area of the same size is Toivala, which in part overlaps Area 2 of the earlier paper, and has similar general features.

Measurements were made in Toivala very much on the same lines as in Evo earlier. It is essential that information on the growing stock can be computed by squares of 100 square metres, 10 000 in total. For this purpose, the D.B.H. of all trees of not less than 10 cm. was measured, and that of smaller trees on 20 or 25 sq.m. in each square. Variable plots, with the application of BAF 4 for sq.m./ha. (equals 17.424 for sq.f./acre), and in general 30 m. apart, were measured, 1 092 in total. The number of sample trees for volume calculations was 2 914. The stand characteristics classified, and the average size of stands, were the same as in Evo.

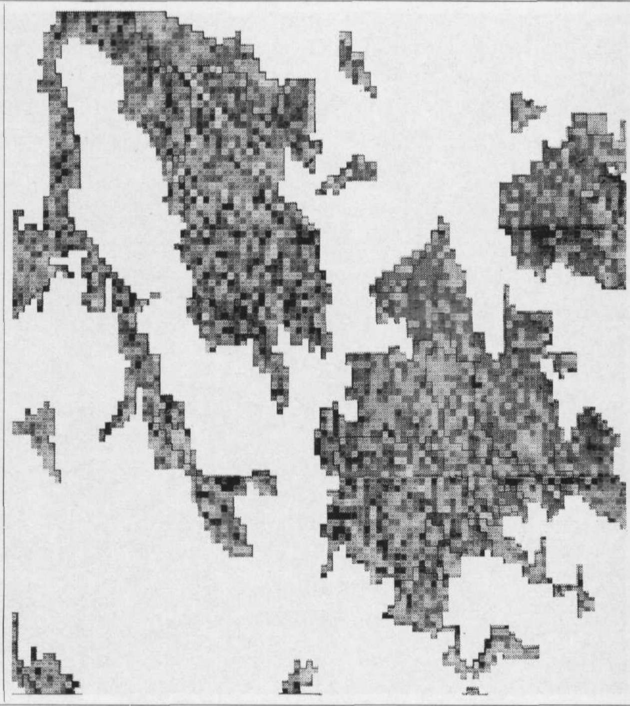
In the following set-up, figures are indicated in respect of the volume of the growing stock and number of stems:

	Evo	Toivala
Volume, cu.m./ha. incl. bark		
total	151	131
D.B.H. more than 20 cm.	120	95
Stem number/ha		
total	686	1141
D.B.H. between 2 and 10 cm.	295	674
» between 10 and 20 cm.	204	289
» more than 20 cm.	187	178

Since the volume percentages of the trees of a D.B.H. exceeding 20 cm., are 80 and 73, respectively, and in the eastern half of Southern Finland commonly 55 to 60 (KUUSELA and SALOVAARA 1968, p. 48), the trees on test areas are relatively large in size. Moreover, the growing stock volumes are rather high in these areas.

No. 1

No. 3



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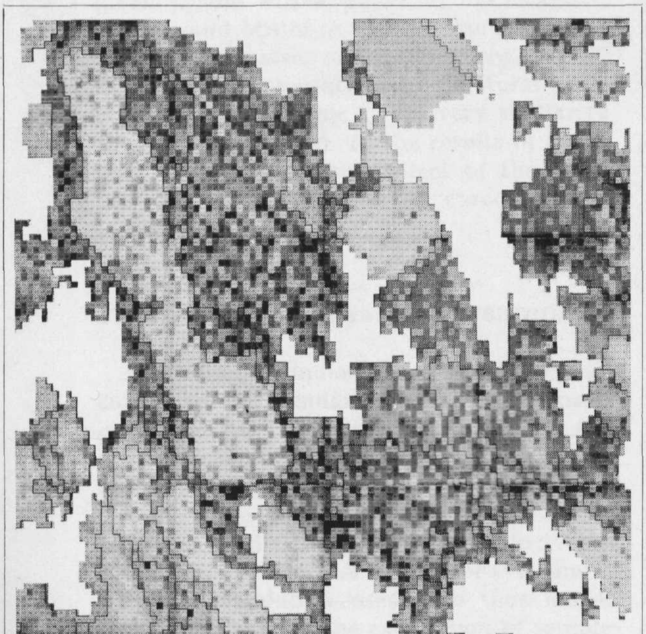
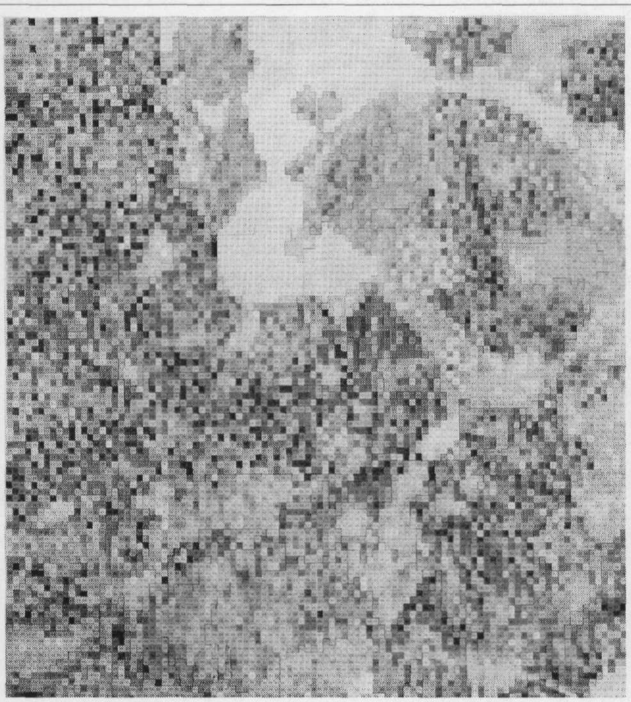


Fig. 1. Mosaic maps of the growing stock volumes in Evo. Nos. 1 to 3 explained on p. 6. Higher volumes are indicated by darker dots; black ones refer to the 100 sq.m. plots with a volume more than 300 cu.m./ha. (The deviation from the square is due to the form of printer output.)

No. 1



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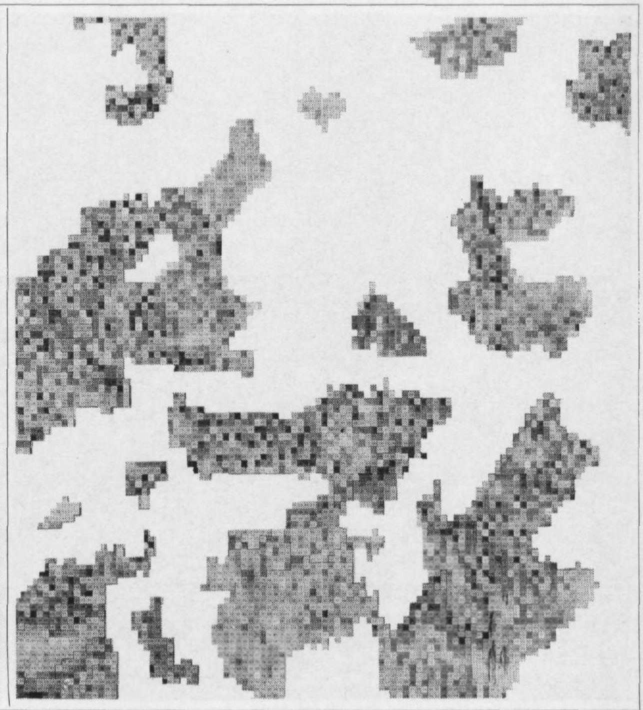

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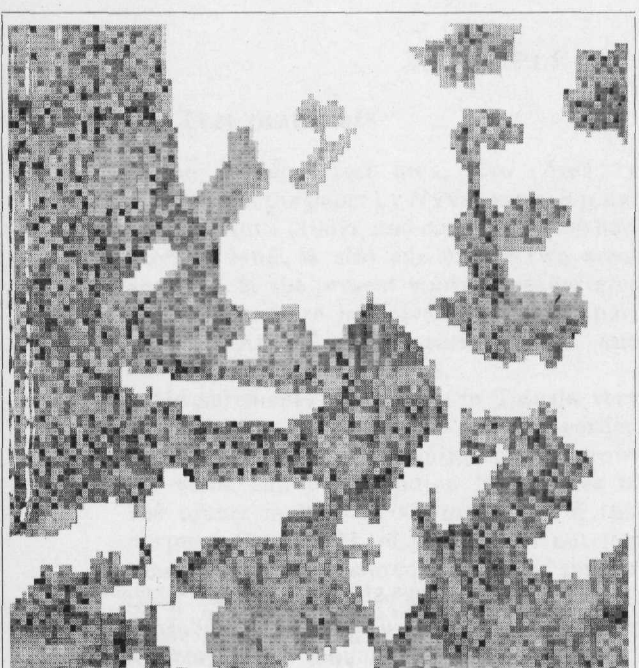

Fig. 2. Maps of the growing stock volumes in Toivala. Cf. Fig. 1.

Table 1. Area percentages, mean volumes and standard deviations of different size plots, by treatment classes and in total in Toivala.

Treatment class	Area percentage	Mean volume	Plots size in 100 sq.m. 1	2	4	9
			Standard deviation			
		cu.m./ha.				
0	7.4	0	0	0	0	0
1	7.5	60.4	54.9	50.6	48.0	42.2
1y	11.7	86.7	77.6	59.8	53.2	45.8
2	7.5	155.5	91.0	74.6	60.7	52.8
3	42.2	169.1	87.0	69.5	56.5	48.5
4	17.0	177.7	86.4	65.6	52.0	43.5
5	2.3	87.6	63.8	57.9	39.2	31.9
6	4.4	56.6	53.8	46.5	46.8	40.5
Total	100	131.2	97.4	83.6	75.6	69.1

Figs. 1 and 2 provide a general impression of the distribution of growing stock volumes in both areas. Furthermore, the Toivala data, like the Evo data, are available on punched cards at the Department of Forest Mensuration and Management of the University of Helsinki.

Table 1 includes further information from Toivala; corresponding figures from Evo were given in the earlier paper by Nyyssönen, Kilkki and Mikkola (1967). The treatment classes were also explained there (p. 6). Coefficients of variation on the total area, calculable from Table 1, are very similar to those in Evo (p. 19). In the results of single treatment classes, some effect of the small size and irregular shape of stands is discernible.

22. Simulation of systematic sampling

No general formulae are available for calculation of the standard error of sample mean in systematic sampling. However, in the present studies it has been possible to make an empirical calculation of this error, by virtue of the total tally of two test areas, using the subdivision of each area into 10 000 squares of 100 sq.m. A number of systematic sampling simulation runs were thus made, to form a basis for the calculation of sample size in different cases. The following plot types were used both in Evo and Toivala:

A. *Simple plots.* All trees with a D.B.H. exceeding 2 cm. were assumed to have been calipered on the whole plot. (As mentioned previously, trees with a D.B.H. less than 10 cm. were tallied on the 1/4 or 1/5 of the area; however, the inherent error is very small.) The plot sizes were as follows:

No. 1. 10 × 10 m. = 100 sq.m.
No. 2. 10 × 20 m. = 200 sq.m. The mean results of the rectangles of that size in both directions were applied
No. 3. 20 × 20 m. = 400 sq.m.
No. 4. 30 × 30 m. = 900 sq.m.

B. *Combination plots.* Trees with a D.B.H. between 2 and 10 cm. are calipered on the area of 25 sq.m., those between 10 and 20 cm. on 100 sq.m., and those exceeding 20 cm. on the whole plot. All the plot sizes mentioned above were used, viz.

No. 5. 10 × 20 m. = 200 sq.m.
No. 6. 20 × 20 m. = 400 sq.m.
No. 7. 30 × 30 m. = 900 sq.m.

In the efficiency comparisons to be made later, it will be assumed that the various size trees are tallied from concentric circles, although sample size data are not exact for such plots; they are based upon square or rectangle plots, and information in respect of trees of less than 20 cm. comes from 100 sq.m. at one end of 200 sq.m. plots, and one corner of 400 sq.m. plots. In 900 sq.m. plots, the small trees have been tallied around the plot centre.

For each of the seven plot types mentioned above, systematic samples with equidistant plots in both directions were taken in Evo and Toivala as follows.

1. In the total area, the distances between plots increasing by 10 m. intervals from 60 to 240 m., and then at 20 m. intervals up to 320 m.; in total, this made 24 plot distances and 7 × 24 = 168 sample types. For 100 and 200 sq.m. plots, the distance 40 m. was also used.

2. In each of the quarter areas, 6 distances were used: 60, 70, 80, 90, 100, and 120 m. This again produced 7 × 4 × 6 = 168 sample types.

With the sample types explained above in use, all the possible samples were taken with a computer in approximately the way described by Nyyssönen, Kilkki and Mikkola (1967, p. 26—28). However, when successive samples were taken, the starting point was moved by only 10 m. for plots larger than 100 sq.m., which resulted in an equal number of samples irrespective of plot size; weighting problems were consequently avoided in regression calculations.

The computations concerned with stratified and strip sampling were similar to those explained in the previous paper (s. 29—30). Non-uniform sampling is described below.

In addition to the calculations made from the original data of both test areas, two lower levels of growing stock were formed, to guarantee a larger variation for regression analyses of simple uniform systematic plot sampling (Chapter 24). This was accomplished by giving a value of zero to the growing stock volume of stands falling in certain treatment classes. The following set-up indicates the mean volumes and forest percentages (i.e. relative tree-bearing areas) in three different cases in Evo and Toivala. Case 1 presents original data. In Case 2, treatment classes 3 and 5 were zeroed in Evo, but all the other classes except 3 and 4 in Toivala. In No. 3 case, only class 4 in Evo, and class 3 in Toivala, were left to grow.

	Mean volume, cu.m./ha.		Forest percentage	
	Evo	Toivala	Evo	Toivala
No. 1	151	131	98	93
No. 2	106	102	73	60
No. 3	86	74	42	43

The above manipulation resulted in an even larger variation on quarter areas: the mean volumes varied in Evo from 26 to 199, and in Toivala from 38 to 155 cu.m./ha., and the forest percentages between 16 and 100 in Evo, and 29 and 100 in Toivala.

A general picture of the growing stock in these different cases is indicated in Figs. 1 and 2. In particular there is observable the location of tree-bearing and treeless areas.

23. Comparison between some forms of systematic and random sampling

The primary task of this paper is that of presenting the results in respect of systematic sampling. In part, the research task could be limited in this way, on the foundation of comparisons of different sampling methods made in the previous study (Nyyssönen, Kilkki and Mikkola 1967, p. 30—37). Although such comparisons can not here attain corresponding importance, there might be reason

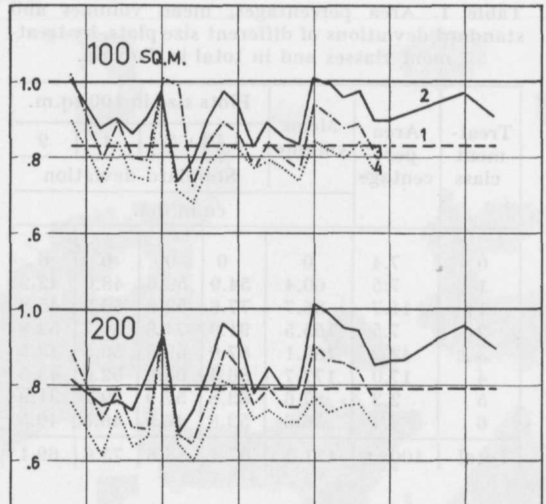

Fig. 3. Ratio of standard errors in estimation of the growing stock volume in Toivala by different plot sampling methods. The values for simple random sampling are equal to 1.0.

Curve 1: stratified random
» 2: simple systematic
» 3: stratified systematic, strata-areas from map
» 4: stratified systematic, strata-areas from line measurement.

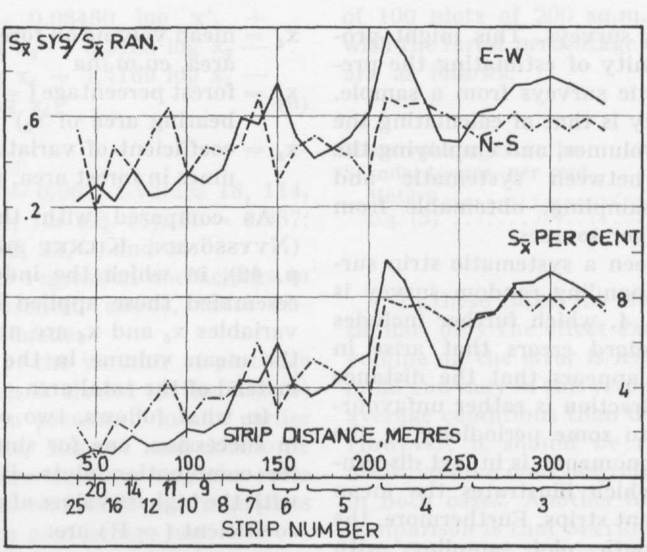

Fig. 4. Standard error in systematic strip sampling ($s_{\bar{x}\,sys}$), and ratio of that and the error of the corresponding random sampling ($s_{\bar{x}\,sys}/s_{\bar{x}\,ran}$) in Toivala.

to emphasize a couple of additional features which are of practical importance.

Fig. 3 indicates the results obtained from the original Toivala data in regard to various plot sampling methods. Each plot size is comparable as a function of the number of plots, and simultaneously as a function of the distance between plots in uniform systematic surveys. It might be of interest to notice that the relative standard error of different forms of systematic sampling is least in stratified sampling in which strata-areas are obtained free of error from a map. This is followed by the case in which the strata-areas are based upon measurements on survey lines, whereas simple systematic survey gives errors which are somewhat higher. This is, of course, in accordance with the extent of information needed in different cases, and also provides hints on the utilization of additional information in practical inventories.

When plot numbers common in practice are used, the standard error of simple systematic surveys seems rather close to that of

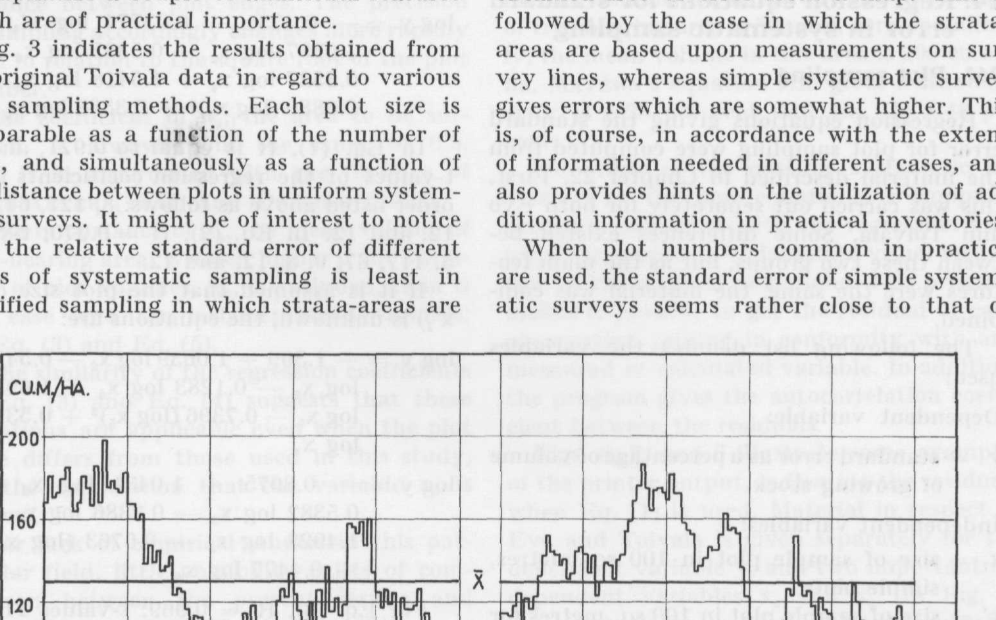

Fig. 5. Mean volumes on different strips in Toivala.

stratified random surveys. This might provide one opportunity of estimating the precision of systematic surveys from a sample. Another possibility is that of calculating the variance of plot volumes, and employing the average ratios between systematic and simple random sampling, obtainable from the figure and other sources.

The ratio between a systematic strip survey and a corresponding random survey is indicated by Fig. 4, which further includes the relative standard errors that arise in strip surveys. It appears that the distance 210 m. in E-W direction is rather unfavourable, and refers to some periodicity in the material. This phenomenon is in fact discernible in Fig. 5, which illustrates the mean volumes on different strips. Furthermore, the results of systematic plot sampling, with plots located at distances of 100 and 200 m. (Fig. 3), fit into the same system.

24. Regression equations for standard error in systematic sampling

241. Plot sampling

Regression equations giving the standard error for plot sampling were computed from the material described in Chapter 22. First, this was carried out separately for both Evo and Toivala. Some differences existed between these two groups, but as the main features were the same, the material was combined.

The following list denotes the variables used:

Dependent variable:

y = standard error as a percentage of volume of growing stock

Independent variables:

x_1 = size of sample plot in 100 sq. metres, simple plots

x'_1 = size of sample plot in 100 sq. metres for trees with D.B.H. exceeding 20 cm., combination plots (on these plots, trees D.B.H. less than 10 cm. are always supposed to be tallied on an area of 25 sq.m., and trees of D.B.H. between 10 and 20 cm. on a 100 sq.m. area)

x_2 = distance of sample plots, m. — square root of the plot size in sq.m.

x_3 = area of survey unit, hectares

x_4 = mean volume on forest (= tree-bearing) area, cu.m./ha

x_5 = forest percentage (= percentage of tree-bearing area of x_3)

x_6 = coefficient of variation of the plot volumes in forest area, per cent.

As compared with the previous paper (NYYSSÖNEN, KILKKI and MIKKOLA 1967, p. 48), in which the independent variables resembled those applied by MATÉRN (1961), variables x_5 and x_6 are new, and x_4 refers to the mean volume in the tree-bearing area, instead of the total area.

In what follows, two equations are given in succession, one for simple, and the other for combination plots. First, the equations with the highest values of multiple correlation coefficient (= R) are:

$$\log y = -0.7784 - 0.06522 \log x_1 + 1.0595 \log x_2 - 0.5389 \log x_3 - 0.3142 \log x_4 + 1.7677 \log x_5 - 0.7569 (\log x_5)^2 + 0.3845 \log x_6 \quad (1)$$

$$\log y = -0.4331 - 0.03774 \log x'_1 + 1.0397 \log x_2 - 0.5335 \log x_3 - 0.3527 \log x_4 + 1.5418 \log x_5 - 0.6880 (\log x_5)^2 + 0.3563 \log x_6 \quad (2)$$

In Eq. (1), R is equal to 0.971, and the t-values of the regression coefficients in the order listed above as follows: 8, 121, 64, 8, 8, 12, and 12. In Eq. (2), R = 0.970; t-values 5, 117, 67, 9, 8, 12, and 12.

If it is assumed that the plot size (x_1 or x'_1) is unknown, the equations are:

$$\log y = -1.399 + 1.0639 \log x_2 - 0.5472 \log x_3 - 0.1283 \log x_4 + 1.6934 \log x_5 - 0.7396 (\log x_5)^2 + 0.5398 \log x_6 \quad (3)$$

$$\log y = -0.8075 + 1.0431 \log x_2 - 0.5382 \log x_3 - 0.2386 \log x_4 + 1.4928 \log x_5 - 0.6763 (\log x_5)^2 + 0.4477 \log x_6 \quad (4)$$

For Eq. (3), R = 0.969; t-values 118, 64, 4, 7, 11, and 21; for Eq. (4), R = 0.969; t-values 117, 67, 7, 7, 12, and 17.

If the standard deviation of the plot volumes is excluded, the equations take the following forms:

$$\log y = 0.6688 - 0.1269 \log x_1 + 1.0596 \log x_2 - 0.5209 \log x_3 - 0.6377 \log x_4 + 1.6534 \log x_5 - 0.7182 (\log x_5)^2 \quad (5)$$

$$\log y = 0.9532 - 0.08460 \log x'_1 + 1.0396 \log x_2 - 0.5185 \log x_3 - 0.6615 \log x_4 + 1.4169 \log x_5 - 0.6486 (\log x_5)^2 \quad (6)$$

For Eq. (5), $R = 0.967$; t-values 18, 114, 59, 20, 7, and 11; for Eq. (6), $R = 0.967$; t-values 14, 111, 62, 23, 7, and 11.

In regard to the regression coefficients in the equations presented above, these observations may be made:

The coefficient of the variable of plot size x_1 in Eq. (5) which is closest to the Eq. (8) from the Evo data presented in the earlier study (NYYSSÖNEN, KILKKI and MIKKOLA 1967, p. 49), is now smaller; i.e., the ratio between the numbers of small and large plots required in a given case is here less.

In all the equations, the coefficient of x_2, the variable that represents plot intervals, is rather similar, being a little more than 1 in value. It should be noticed, that x_2 means the distance between plot edges. The precision of sampling accordingly changes more rapidly than in relation to the square root of the plot number.

The coefficient of x_3, the area to be surveyed, is always about the same, or 0.5. This is in accordance with the findings of LANGSAETER (1932) and ÖSTLIND (1932).

The importance of x_4, the mean volume of tree-bearing area, is much higher if the variation of plot volumes, x_6, is excluded, than is the case with the last-mentioned variable; cf. Eq. (3) and Eq. (5).

The similarity of the regression coefficients of Eq. (3) and Eq. (4) suggests that these equations are applicable even when the plot type differs from those used in this study, on the supposition that the variable x_6 is known.

For lack of empirical studies in this particular field, little possibility exists of comparison between the present results and others. Nevertheless, MATÉRN's (1961) paper can be discussed here. With ÖSTLIND's (1932) study in mind, MATÉRN presented (p. 17) »an especially home-made» formula for the standard error of line-plot survey; the independent variables were forest land area, mean volume, plot size, and line and plot intervals. The results obtained from MATÉRN's equation, and those given by Eq. (5) for the case of 100 plots of 200 sq.m. on 100 hectares, with the forest percentage assumed to be 100, are as follows:

Mean volume, cu.m./ha.	100	150
Standard error, per cent		
Matérn	6.28	5.34
Eq. (5)	6.58	5.08

In these cases, the level of error is quite similar; only the effect exerted by the mean volume on the error is less in MATÉRN's formula and may in this respect better represent average conditions than do the present data. However, it should be remarked that the mean volume does not refer to the same area in both cases. Another feature of interest in comparison is that MATÉRN's equation might underestimate the standard error in cases where the forest includes treeless areas, without exact information on their area. For example, if in the above example other factors remain the same, but the percentage of tree-bearing area is 50, and, correspondingly, the mean volume in this area is 200 cu.m./ha, MATÉRN's equation still gives a standard error of 6.28 per cent, but Eq. (5) 8.48 per cent.

For study of the possible systematic deviations of the new equations, a computer program connected with the regression analysis was prepared, to facilitate visual inspection of the residual deviations. This program makes it possible to get the residual of each observation printed in conformity with any measured or calculated variable. In addition, the program gives the autocorrelation coefficient between the residuals.

Figs. 6, 7, and 8 illustrate some examples of the printer output, indicating the residuals when Eq. (1) is used. Material in respect of Evo and Toivala is given separately for the dependent variable y, and two important independent variables x_2 and x_3. In Fig. 6, the residuals have been plotted against the fitted values, i.e., the values given by Eq. (1), while in Figs. 7 and 8 the plot is against the original values of the corresponding independent variables (cf. DRAPER-SMITH 1966, p. 90—91). In addition, the scale on the x-axis in Fig. 6 is in logarithmic form, but in arithmetic form in Figs. 7 and 8.

It is apparent from Fig. 6 that systematic

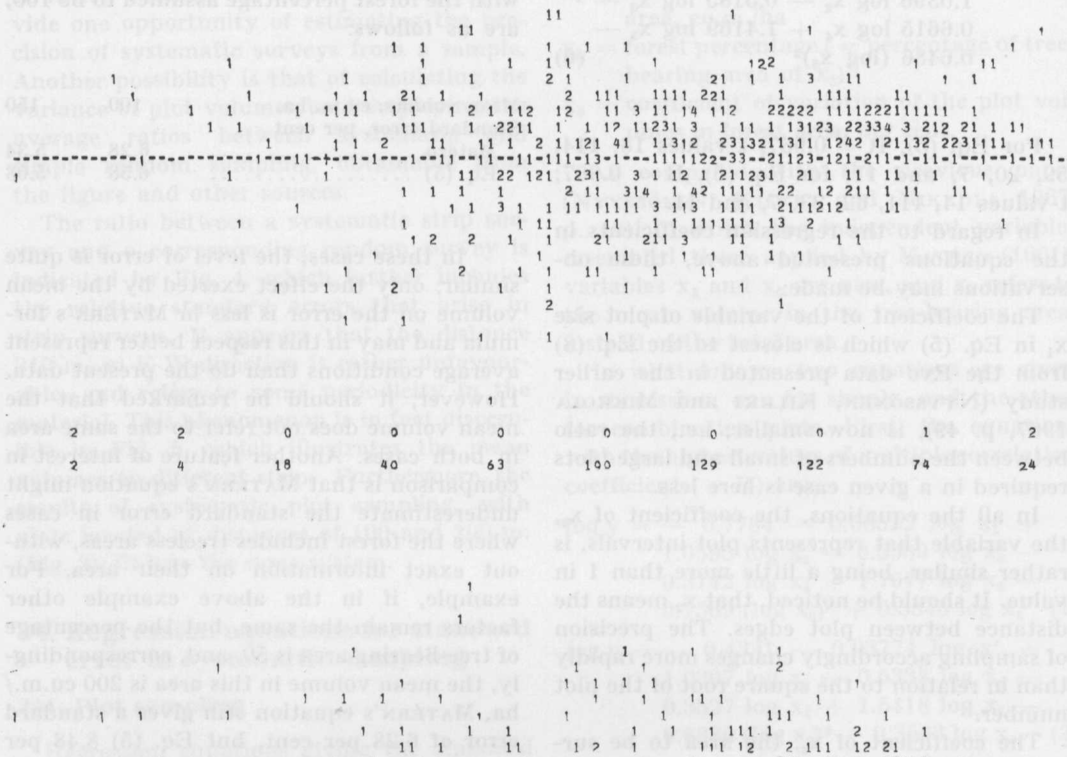

Fig. 6. Relative distribution of the residuals from Equation (1) in Evo (top) and Toivala (bottom) material. x-axis variable, the logarithm of standard error as a percentage of the mean volume (y) goes from −0.03742 to 1.65072 (from 0.92 to 44.74 per cent) in Evo, and from −0.01571 to 1.62827 (from 0.97 to 42.49 per cent) in Toivala. Below each set of figures: number of observations in ten equally wide groups with the group means.

under- or overestimation of error occurs only for extreme values of standard error. Furthermore, the different figures seem to indicate that Eq. (1) fits both sets of material almost equally well.

242. Strip sampling

On application of the same type of regression calculation as that used earlier for Evo (NYSSÖNEN, KILKKI and MIKKOLA 1967,

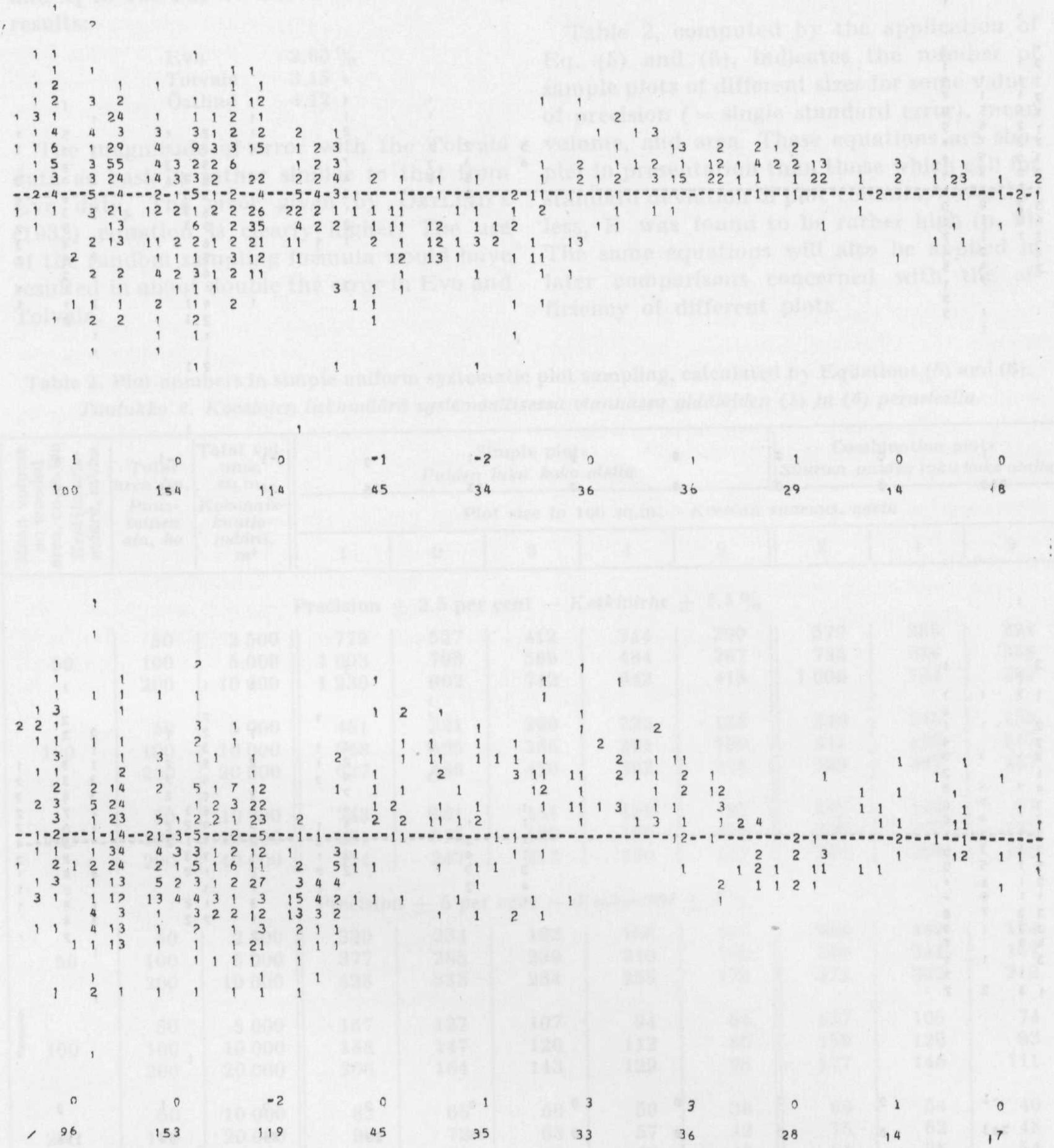

Fig. 7. Relative distribution of residuals from Equation (1) in Evo (top) and Toivala (bottom) material. x-axis variable, distance between the plot edges (x_2) from 20 to 310 metres. Below each set of figures: number of observations in ten equally wide groups with the group means.

p. 53), the following equation was derived from Toivala data for strip sampling:

$$\log y = 2.3504 + 0.8371 \log x_2 - 0.4400 \log x_3 - 1.2521 \log x_4 \quad (7)$$

Here, x_2 means strip interval minus strip width in metres, x_3 the area of survey unit in hectares, and x_4 the mean volume in cu.m./ha. R is equal to 0.895, and the t-values of regression coefficients 19, 9, and 4. The coefficient of x_2 is only slightly smaller than that for Evo. The same is also true for the coefficient of x_3; the average for both areas is about 0.5, and thus the same as that presented by Öst-

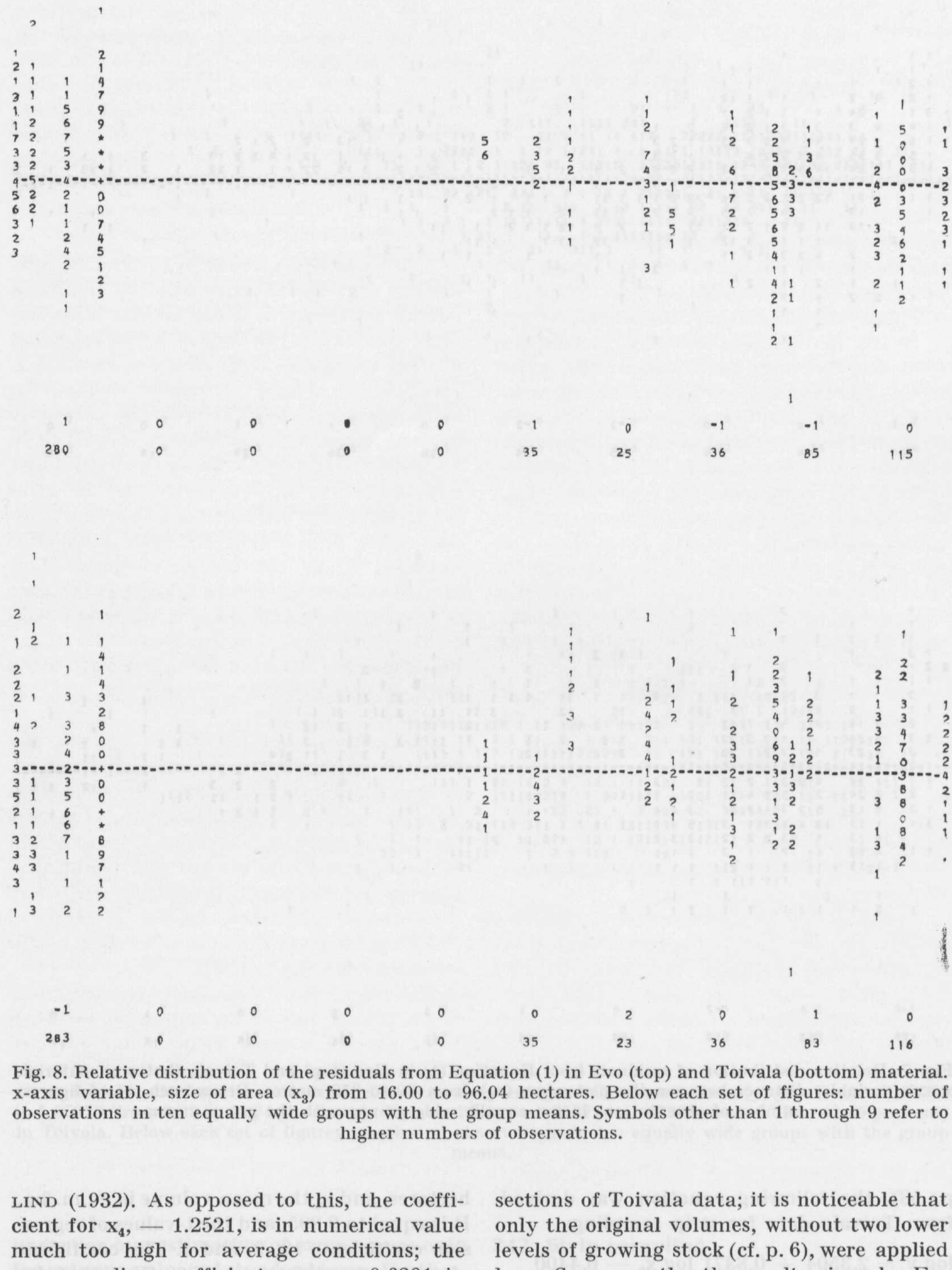

Fig. 8. Relative distribution of the residuals from Equation (1) in Evo (top) and Toivala (bottom) material. x-axis variable, size of area (x_3) from 16.00 to 96.04 hectares. Below each set of figures: number of observations in ten equally wide groups with the group means. Symbols other than 1 through 9 refer to higher numbers of observations.

LIND (1932). As opposed to this, the coefficient for x_4, — 1.2521, is in numerical value much too high for average conditions; the corresponding coefficients were —0.6201 in Evo and —0.4 in ÖSTLIND's (1932) material. The present result seems to be attributable to the small variation in the different quarter-sections of Toivala data; it is noticeable that only the original volumes, without two lower levels of growing stock (cf. p. 6), were applied here. Consequently, the results given by Eq. (7) are comparable only with other results on the level of Toivala growing stock, 130 cu.m./ha. If we assume that x_2 is equal to 110 m.

and x_3 to 100 ha, we arrive at the following results:

Evo	2.63 %
Toivala	3.15 »
Östlind	4.12 »

The magnitude of error with the Toivala data as basis is rather similar to that from Evo data. The error given by ÖSTLIND's (1932) equation is clearly higher. The use of the random sampling formula would have resulted in about double the error in Evo and Toivala.

25. Sample size in plot sampling

Table 2, computed by the application of Eq. (5) and (6), indicates the number of sample plots of different sizes for some values of precision (= single standard error), mean volume, and area. These equations are simpler in presentation than those which call for standard deviation of plot volumes; nevertheless, R was found to be rather high (p. 9). The same equations will also be applied in later comparisons concerned with the efficiency of different plots.

Table 2. Plot numbers in simple uniform systematic plot sampling, calculated by Equations (5) and (6).

Taulukko 2. Koealojen lukumäärä systemaattisessa otannassa yhtälöiden (5) ja (6) perusteella.

Mean volume on wooded area, cu.m./ha *Keskikuutiomäärä, m³/ha*	Total area, ha. *Puustoinen ala, ha*	Total volume, cu.m. *Kokonaiskuutiomäärä, m³*	Simple plots *Puiden luku koko alalta*					Combination plots *Suurten puiden luku koko alalta*		
			Plot size in 100 sq.m. – *Koealan suuruus, aaria*							
			1	2	3	4	9	2	4	9
			Precision ± 2.5 per cent – *Keskivirhe ± 2.5 %*							
	50	2 500	779	527	412	344	200	579	383	224
50	100	5 000	1 003	708	569	484	297	785	546	338
	200	10 000	1 230	902	742	642	415	1 006	734	482
	50	5 000	451	321	260	222	138	349	246	155
100	100	10 000	548	405	335	291	190	441	325	217
	200	20 000	637	486	410	362	248	529	407	287
	50	10 000	243	181	151	131	87	192	144	97
200	100	20 000	281	215	183	162	112	228	177	127
	200	40 000	314	247	213	190	137	260	209	156
			Precision ± 5 per cent – *Keskivirhe ± 5 %*							
	50	2 500	320	234	192	166	107	260	189	124
50	100	5 000	377	285	239	210	142	318	241	167
	200	10 000	428	333	284	253	178	371	292	212
	50	5 000	167	127	107	94	64	137	105	74
100	100	10 000	188	147	126	112	80	159	126	93
	200	20 000	206	164	143	129	95	177	145	111
	50	10 000	82	65	56	50	36	68	54	40
200	100	20 000	90	72	63	57	42	75	62	48
	200	40 000	96	78	69	63	48	81	68	54
			Presicion ± 10 per cent – *Keskivirhe ± 10 %*							
	50	2 500	112	87	74	66	46	96	76	55
50	100	5 000	124	98	85	77	56	109	88	67
	200	10 000	134	108	95	86	65	119	99	78
	50	5 000	54	43	37	34	25	46	38	29
100	100	10 000	58	47	41	38	28	50	42	33
	200	20 000	62	50	45	41	32	53	45	37
	50	10 000	25	20	18	16	12	21	18	14
200	100	20 000	27	22	19	18	14	22	19	16
	200	40 000	28	23	21	19	15	23	20	17

Since other methods will be used in surveying small areas with great precision, the minimum area in Table 2 is 50 ha. The maximum, 200 ha., involves some extrapolation from the basic data, but the coefficient for the area seems rather reliable (p. 9).

In general, the numbers of combination plots are some 10 per cent higher than those of corresponding simple plots. The 400 sq.m. combination plots need be measured in about the same number as 300 sq.m. simple plots.

Table 2 illustrates the case in which the percentage of tree-bearing area is 100. Although the relevant equations have been based on square-formed areas, it may be reasonable to assume that equal plot numbers apply to irregulary shaped and partially stocked forest areas as well, on the assumption that the tree-bearing area is accurately determinable from a map or aerial photograph. If this is not the case, more plots are required from the same tree-bearing area if a given degree of precision is needed (cf. also p. 9). To illustrate this point, computations were made of the number of sample plots, on the assumption of a percentage of 50 for tree-bearing area ($x_5 = 50$). A calculation was then made of the increased percentage in respect of forest plot numbers in various cases, as compared with the corresponding plot numbers if x_5 were equal to 100 and x_3 half of the previous area; the total volume of the growing stock was equal in all the pairwise comparisons. The percentage, which in a way indicates the gain from stratification into two strata (treeless and tree-bearing) varied between 25 and 80 in different cases. The result consequently reveals that exact information on the size of tree-bearing area is an efficient means in reduction of the plot number needed for a given degree of precision.

3. TIME STUDIES

31. Factors affecting total costs

Various types of equations for calculation of the costs incurred in plot surveys have been presented (see Strand 1957; Nersten 1967, p. 382). For the purposes of the present investigation, the following equation, rather similar to that put forward by Nersten, can be considered:

$$C = c_0 + c_1 n_1 f(a) + c_2 n_1 + c_3 d + c_4 n_2 \quad (8)$$

where C = total cost
c_0 = constant for fixed cost (equipment, computations, overhead)
$c_1, c_2 \ldots$ = unit costs of different items
d = traveling distance in units of measurement
n_1 = number of sample plots
$f(a)$ = function showing dependence of tree tally time on plot type
n_2 = number of sample trees

With the efficiency of an appropriate line-plot survey of a given, required precision borne in mind, the first and the last of the variables may frequently be disgarded. Fixed costs have no bearing upon the divergences between methods. Similarly, the number of sample trees and the cost of the work thus incurred can be considered as constant, despite the obvious variation in the number of sample trees dependent upon the precision of the inventory.

Later, the importance of the variables of the equation will be analysed, for the most part in the form of time used, and the material measured for this purpose will be discussed. The most laborious of the studies proved to be that concerned with the time needed for tree tally on sample plots, and the associated definition of plot perimeter. Attention will also be paid to other aspects, including the time needed to measure sample trees.

32. Tree tally

321. Measurements made

Most of the time studies was carried out in three areas in 1961. First, in Toivala, studies were concerned with the time required for tree tally on the following circular plots: 100, 200, 300, 500 and 1 000 sq.m. In addition, square plots of the same sizes, and variable plots with BAF 1 and BAF 2 (sq.m./ha.), were studied. All the uncertain borderline trees were checked by caliper and measuring tape.

In general, each plot type was measured at 64 locations, distributed in different treatment classes. To eliminate the effect of familiarity with the area, plots of the same type at different locations were measured consecutively. In total, 748 plots were measured.

Secondly, the same types, 7 in all, of circular and variable plots were measured in Meltaus (cf. Nyyssönen, Kilkki and Mikkola 1967, p. 8). The measurements were made from 115 central points, and 805 plots were measured in total.

The third place for time studies in 1961 was the line-plot survey in the forest inventory of a timber company. The plot size was 138.5 sq.m., and the plot distance 200 metres. In all, the course of work was followed on a line length of 21.6 km. during one week. In addition to tree tally time, the following times were recorded: movement from one plot to another, sample tree measurements, preparation for measurements, pauses, etc.

In 1962, studies were concentrated on the time required for strip surveys; these studies were made in both Toivala and Meltaus. The length of the 10 m. wide strip enumerated in Toivala was 9.7 km., and that in Meltaus 11.7 km. Repetition of the time studies was made on 103 old plots to enable the results of new measurements to be linked with the time data determined earlier.

In 1963, the main objective was that of compiling material for comparative studies concerned with variable plots of large BAF. Consequently, variable plots of BAF 2 and BAF 4 were measured at 56 points. The results of these studies have already been published (Nyyssönen and Kilkki 1965).

In 1966, two types of time studies were engaged in. In Toivala, the main idea was that of acquiring information from concentric circular plots, with larger trees being tallied on larger areas. In total, 200 plots were measured. Secondly, in a line-plot survey in the forests of another timber company, the different phases of work were recorded separately. The plot size was 300 sq.m., and the total length of survey line used in the study 11.2 km.

The crew responsible for these plot measurements comprised a leader and 2 or 3 assistants. In strip survey, the crew comprised a leader and 4 assistants. In the inventory of company-owned forests, a crew leader had 3 or 4 men to help him. Corrections in regard to the times recorded in different size crews were necessary in comparison of the results. Consequently, the results presented in Chapter 322 assume a crew of 1 leader and 3 assistants.

322. Discussion of the results

First of all, knowledge was required of the relationship between circular and square plots of a given size. Both of these plots were measured in Toivala. With seedling and sapling stands excluded, the average times required for square plots are as follows, when a value of 1.00 is given to circular plots of corresponding sizes:

Plot size, sq.m.	Relative time
100	2.58
200	2.35
300	1.96
500	1.89
1,000	1.71

Consequently, the times for square plots are always longer than those for circular ones. In particular, a small-sized square plot cannot be used to best advantage. As a result, square plots could be ignored in continuance of the study, and attention paid solely to circles as representatives of fixed-area plots.

The factors which contribute to the time spent on circular plots, all the trees tallied in the total area, were studied by means of regression analysis. The time required for plots of different sizes could be described by one equation. The best fit was obtainable with equations containing the logarithm of plot time as a dependent variable, and the logarithms of plot size and number of trees on the plot as independent variables. In view of the correlation between plot size and number of trees, one might think that the number of trees per ha. could have been better.

The following equation was derived from the 310 circular plots of Toivala:

$$\log y = 1.253 + 0.786 \ \log x_1 + 0.250 \ \log x_2$$

where y = time per sample plot, 1/100 minutes
x_1 = number of stems per plot + 1
x_2 = size of sample plot in 100 sq. m.

The equation from the 575 circular plots of Meltaus is as follows:

$$\log y = 1.181 + 0.741 \log x_1 + 0.279 \log x_2 \quad (9)$$

Examination of the results derived by application of the former equation, and comparison with Equation (9) proved that the time spent was longer in Toivala than in Meltaus, mainly because of the lack of experience, as the work was started in Toivala. In addition, for the same obvious reason the need for time had changed during the course of the work in Toivala. It was thus decided to apply Equation (9) in the efficiency calculations of this study. For this equation, the multiple correlation coefficient R was found to be 0.982. The values of t for regression coefficients were 76 and 20.

Next in order are the concentric combination plots of the type mentioned under B, p. 5. The equation calculated for them assumes the following form, after correction to the level of Equation (9) had been introduced:

$$\log y = 1.236 + 0.853 \ \log x_1 + 0.156 \log x_2 \quad (10)$$

where x_2 = size of the largest circle in 100 sq.m. R equals 0.921, and the t-values of regression coefficients are 15 and 3.

As regards the variable plots, the time studies carried out at Toivala in 1961 have been discarded for the reasons explained above, and the equations calculated from the material compiled at Meltaus, and at Evo in 1963. The expenditure of time on these plots is attributable to definition, with the aid of the relascope, of trees to be tallied and to the measurement of tree diameters. The former phase is connected with the checking of doubtful border trees by means of tape and caliper. Since large systematic differences were apparent in the results of variable plot surveys (cf. Nyyssönen, Kilkki and Mikkola 1967, p. 16—18), this necessitates inclusion of the time needed to check border trees as a variable in the equation, if relascope measurements are to be utilized.

An attempt was made to characterize the time of measuring variable plots by the number of trees, number of border trees, mean diameter of trees, BAF and plot size, with the latter computed from the mean diameter and BAF. However, the diameter was not a significant variable and the time needed on BAF 1 and BAF 2 plots could be expressed by the following equation:

$$y = 0.470 + 0.106 \, x_1 + 0.478 \, x_2 \quad (11)$$

where y = time per sample plot, minutes
x_1 = number of stems per sample plot
x_2 = number of trees checked with caliper and measuring tape

The multiple correlation coefficient R = 0.940, and the t-values for regression coefficients, were 24 and 22 respectively.

The results in respect of the BAF 4 plots, also given in an earlier paper (Nyyssönen and Kilkki 1965), were as follows:

$$y = 0.159 + 0.0949 \, x_1 + 0.388 \, x_2 \quad (12)$$

The multiple correlation coefficient R = 0.889, and the t-values of the regression coefficients were 8 and 10, respectively. A comparison of Equations (11) and (12) reveals that the time needed per tree, exclusive of clearing time, is considerably less for BAF 4 than for BAF 1 and BAF 2. This might find its explanation in the fact that, on the BAF 4 plots, trees are close to the central point, which reduces the time of travel from tree to tree.

The times measured in strip survey were broken down into stands which were used as units of observation. The time expenditure is expressed by an equation, with the time needed for a strip of certain length as a dependent variable, and the number of trees as an independent variable. Of the 21.4 km. measured, a proportion of the early strips was discarded to eliminate the effect of inexperience from the results of the work. The strips included comprise 110 stands. The equation giving the time expenditure is as follows:

$$y = 3.511 + 0.00586 \, x \quad (13)$$

where y = time in minutes per 100 metres
x = number of stems per hectare

The multiple correlation coefficient R = 0.936, and the t-value of the regression coefficient was 28.

All the results indicated by Equations (9) to (13) inclusive are based upon times observed in experimental work. On comparison of the results indicated by Eq. (9) with the time spent on tree tally in the company forest inventories mentioned earlier, with consideration also given to the stem number and crew size, it was found that the time consumption was about 2.7 times as great as that in practical inventories. In practice, accordingly, there are lost periods of time which can be eliminated in the time studies arranged for tests. Consequently, in calculations made for comparisons of efficiency, the results shown in the above equations have been multiplied by 2.7, and the times that elapsed in other phases of the work have been assumed equivalent to their requirement in company inventories.

The tree tally times indicated by Table 3 were found for some plot sizes by the application of Equations (9) and (10), and of multiplier 2.7, and by assumption of the average stem numbers of the Evo and Toivala areas. The tree numbers mentioned earlier (p. 4) were applied irrespective of the level of growing stock, since calculations made for illustration of this point indicated that the tree numbers were rather similar in each forest area, even with variation in the mean volume of total area.

The results listed in Table 3 have great importance in later comparisons. In regard to simple plots, the time requirement is approximately proportional to the plot size, whereas this is not the case with combination plots. By reason of the difference in conditions, it is rather difficult to compare the above results, say with those reported by NERSTEN (1967, p. 383). For this study, importance is attached to the different times used being mutually comparable.

Table 3. Average times for tree tally, including definition of the plot perimeter.

Taulukko 3. Koealojen rajoituksen ja puiden luvun vaatima keskimääräinen aika.

Plot size in 100 sq.m. *Koealan suuruus, aaria*	Simple plots *Puiden luku koko alalta*		Combination plots *Suurten puiden luku koko alalta*	
	Evo	Toivala	Evo	Toivala
	Time in minutes — *Aika, minuuttia*			
1	1.88	2.64		
2	3.64	5.20	2.89	3.41
4	7.20	10.39	4.55	5.03
9	16.23	23.56	8.64	8.99

33. Additional factors of total time

The third term on the right side of Eq. (8), p. 14, refers to the costs in relation to the number of sample plots, irrespective of their size. The time needed might be called »clearing time», and includes such phases as the location of the sample plot centre and preparation of the instruments for measurement and for traveling to the next plot. On the average, these took 1.9 minutes on forest plots in one company inventory, and 4.3 minutes in the other. The mean of these two averages will not be applied in later comparisons, but rather two alternatives of 2 and 4 minutes.

In computing the traveling distance, it has been assumed that the area to be surveyed is a square. In addition to travel along the lines, the transition from one line to another and return to the starting point, i.e. double the side of a square, without waste time, is included. Thus, the traveling distance in 100 metres (d) can be expressed by the following equation:

$$d = \sqrt{n \cdot A} + 2\sqrt{A},$$

where A = the area to be surveyed in hectares, and
n = plot number.

In the inventories of companies' forests, the times needed per 100 m. in line measurement were 4.56 and 3.94 minutes, respectively. FITJE (1965) found in Norway that the corresponding time for the easiest terrain was 3 minutes, for an average one 4 minutes, and for the most difficult 7 min./100 m. On the basis of these results, the average time of travel was here set at 4 min./100 m.

The time required for sample tree measurements is of minor importance in the present study. Nevertheless, these times also need to be mentioned.

When the tree volume tables of ILVESSALO (1947) are applied, the taper as a difference in diameters at breast and 6-metre height must be measured, along with the tree height. Calipers are employed for both diameter measurements. In common Finnish practice, the estimation of growth carried out simultaneously requires the measurement of bark thickness at breast height and of radial increment during the past 5 years, together with estimation of height growth during the same period.

The average measurement time per sample tree in one company's inventory averaged 2.11 minutes on plots of 2.6 sample trees; this time also includes the measurements needed for growth calculations. In the other company, the average time was 2.23 minutes per tree. These times are accordingly about equal to the time of 2 minutes reported in some Swedish studies (Vid andra . . . 1947, p. 76). It could be ascertained through observations carried out in two ways that the measurements pertaining to the volume alone took an even half of the time stated above.

4. EFFICIENCY COMPARISONS

The sample sizes required to achieve a certain level of precision in an inventory were discussed in Chapter 2, while Chapter 3 dealt with the results of time studies indicating the relative costs in various phases of field work. By utilizing the information contained in these two chapters, knowledge could be obtained of the efficiency of the

Table 4. Optimum size in 100 sq.m. of simple plots (bold face), and survey time in 10 minutes without sample tree and fixed times. Clearing time 4 min./plot.

Taulukko 4. Koealan optimisuuruus aareina luettaessa puut koko koealalta (lihavalla), ja arviointiaika 10 minuutteina ilman kiinteää ja koepuuaikaa. Valmisteluaika 4 min/koeala.

Mean volume on wooded area, cu.m./ha. *Keskikuutiomäärä, m³/ha*	Total area, ha. *Pinta-ala, ha*	Total volume, cu.m. *Kokonaiskuutiomäärä, m³*	Evo tree numbers *Evon runkoluvut*			Toivala tree numbers *Toivalan runkoluvut*		
			Precision, per cent — *Keskivirhe, %*					
			± 2.5	± 5	± 10	± 2.5	± 5	± 10
Forest percentage 100 — *Puustoista alaa 100 %*								
	50	2 500	**5** 442	**3** 226	**2** 99	**3** 549	**2** 265	**1** 110
50	100	5 000	**4** 638	**2** 294	**2** 123	**2** 766	**1** 336	**1** 135
	200	10 000	**3** 865	**2** 369	**2** 153	**2** 1 012	**1** 413	**1** 166
	50	5 000	**3** 296	**2** 134	**2** 57	**2** 352	**1** 153	**1** 62
100	100	10 000	**3** 396	**2** 169	**2** 71	**2** 461	**1** 188	**1** 77
	200	20 000	**2** 508	**2** 209	**2** 90	**1** 578	**1** 229	**1** 97
	50	10 000	**3** 182	**2** 78	**2** 34	**2** 211	**1** 86	**1** 37
200	100	20 000	**2** 231	**2** 97	**2** 43	**1** 262	**1** 106	**1** 96
	200	40 000	**2** 289	**2** 121	**2** 56	**1** 320	**1** 131	**1** 60
Forest percentage 50 — *Puustoista alaa 50 %*								
	50	1 250	**10** 364	**7** 247	**4** 136	**8** 478	**4** 306	**2** 157
50	100	2 500	**10** 607	**5** 367	**3** 183	**5** 778	**3** 440	**2** 207
	200	5 000	**6** 958	**4** 516	**3** 241	**4** 1 186	**3** 604	**2** 268
	50	2 500	**9** 292	**4** 172	**3** 85	**5** 370	**3** 205	**2** 96
100	100	5 000	**6** 453	**3** 240	**3** 112	**3** 555	**2** 275	**2** 124
	200	10 000	**4** 660	**3** 320	**3** 147	**2** 784	**2** 361	**2** 160
	50	5 000	**5** 214	**3** 112	**3** 53	**3** 260	**2** 127	**2** 58
200	100	10 000	**4** 308	**3** 148	**3** 69	**2** 362	**2** 166	**2** 75
	200	20 000	**3** 421	**3** 194	**3** 91	**2** 482	**2** 214	**2** 97

survey. The total time expenditure was calculated for the inventories with plot sizes of 100, 200, 300 etc. sq.m., up to 1 000 sq.m. Of course, the optimum sizes could have been derived by the use of some analytical method, as applied by O'Regan and Arvanitis (1966).

41. Uniform plot sampling

The results in respect of simple systematic uniform plot sampling are indicated in Tables 4 and 5, and in Figures 9 and 10. The precision has always been given as a standard error. The extreme plot sizes to be seen in the tables and figures are 100 and 1 000 sq.m. In fact, the plot sizes from 100 to 900 sq.m. utilized in both growing stock variation and time studies rather well cover the entire range under consideration here.

The common optimum size of simple plots, indicated by Table 4, is 200 sq.m., with clearing (or preparation) time 4 min./plot. If the latter time is only 2 minutes, the average optimum plot is closer to 100 sq.m.

The corresponding optimum size of combination plots is 300 to 500 sq.m. with the Evo tree numbers, and 400 to 600 sq.m. with those of Toivala. If one single size need be mentioned, 400 sq.m. seems to be a good figure.

A reasonable deviation from the optimum plot size does not in general imply a great difference in time expenditure. However, in simple plots, and in cases where the number of small-size trees is essential, a great deal of attention has to be paid to the plot size (cf. Fig. 9).

Both Table 4 and 5 show rather large plot sizes for the areas with a small percentage of the tree-bearing area. In these areas, it has been assumed that the survey lines have been measured on treeless parts at the same in-

Table 5. Optimum size in 100 sq.m. of combination plots (bold face), and survey time in 10 minutes without sample tree and fixed times. Evo tree numbers.

Taulukko 5. Koealan optimisuuruus aareina luettaessa suuret puut koko koealalta (lihavalla), ja arviointiaika 10 minuutteina ilman kiinteää ja koepuuaikaa. Evon runkoluvut.

Mean volume on wooded area, cu.m./ha. *Keskikuutiomäärä, m³/ha*	Total area, ha. *Pinta-ala, ha.*	Total volume, cu.m. *Kokonaiskuutiomäärä, m³*	Clearing time 2 min./plot *Valmisteluaika 2 min/koeala*						Clearing time 4 min./plot *Valmisteluaika 4 min/koeala*					
			Precision, per cent — *Keskivirhe, %*											
			± 2.5		± 5		± 10		± 2.5		± 5		± 10	
Forest percentage 100 — *Puustoista alaa 100 %*														
	50	2 500	**10**	285	**6**	167	**3**	80	**10**	327	**10**	193	**6**	95
50	100	5 000	**9**	442	**4**	228	**3**	103	**10**	506	**7**	270	**4**	121
	200	10 000	**6**	640	**3**	298	**3**	131	**10**	744	**5**	356	**4**	152
	50	5 000	**8**	206	**4**	104	**3**	47			**7**	123	**4**	55
100	100	10 000	**5**	292	**3**	135	**3**	61	**9**	342	**5**	160	**4**	70
	200	20 000	**4**	392	**3**	173	**3**	79	**7**	467	**4**	203	**4**	88
	50	10 000	**5**	134	**3**	62	**3**	29	**9**	157	**5**	73	**4**	33
200	100	20 000	**4**	177	**3**	79	**3**	38	**6**	211	**4**	92	**4**	42
	200	40 000	**3**	228	**3**	102	**3**	50	**5**	272	**4**	116	**4**	54
Forest percentage 50 — *Puustoista alaa 50 %*														
	50	1 250	**10**	228	**10**	165	**9**	102	**10**	259	**10**	185	**10**	114
50	100	2 500	**10**	389	**10**	259	**6**	146	**10**	440	**10**	290	**10**	163
	200	5 000	**10**	637	**9**	388	**5**	201	**10**	719	**10**	433	**8**	225
	50	2 500	**10**	187	**10**	122	**6**	68	**10**	211	**10**	136	**10**	76
100	100	5 000	**10**	302	**8**	180	**5**	93	**10**	340	**10**	201	**7**	104
	200	10 000	**10**	468	**6**	254	**5**	125	**10**	524	**9**	285	**6**	138
	50	5 000	**10**	143	**7**	84	**5**	44	**10**	161	**10**	94	**7**	48
200	100	10 000	**10**	219	**6**	117	**5**	59	**10**	245	**9**	132	**6**	65
	200	20 000	**7**	318	**5**	159	**5**	79	**10**	356	**7**	178	**6**	85

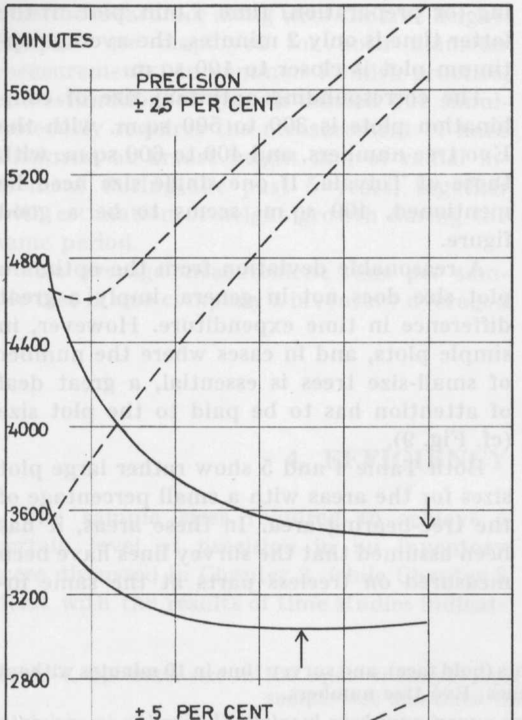

Fig. 9. Survey time as a function of plot size, without sample tree and fixed times. Toivala tree numbers, area 100 ha., forest percentage 100, and mean volume 100 cu.m./ha. Solid lines: combination plots; broken lines: simple plots. Clearing time for each degree of precision: upper curves 4, lower curves 2 min/plot. Optimum plot sizes indicated by arrows.

Kuva 9. Arviointiaika (ilman kiinteää ja koepuuaikaa) koealan suuruuden funktiona. Toivalan runkoluvut, pinta-ala 100 ha, puustoista alaa 100 %, keskikuutiomäärä 100 m³/ha. Yhtäjaksoiset viivat: suurten puiden luku koko koealalta; katkoviivat: kaikkien puiden luku koko koealalta. Valmisteluaika kullakin luotettavuustasolla: ylemmät käyrät 4, alemmat 2 min/koeala. Optimisuuruudet osoitettu nuolilla.

tervals as on tree-bearing parts, but without any stops on sample plots.

Combination plots are more efficient than simple plots, as is evident from the left-hand of Table 4 and the right-hand side of Table 5, and Fig. 9. However, a low precision requirement permits the use of simple plots. It should be noted that if combination plots are used the large and most valuable trees become well surveyed. Mention is due that the calculations made, by way of illustration of the possibility of tallying all the trees with a D.B.H. of more than 10 cm. from the whole plot, indicated that the efficiency of this procedure is inferior to that of the present procedure, in which only those trees with a D.B.H. exceeding 20 cm. are counted on the whole plot area.

A longer clearing time means an increasing plot size (Table 5, Fig. 9).

The larger the area to be surveyed, the smaller is the plot size (Tables 4 and 5, Fig. 10).

A greater requirement for precision means a larger plot size (Tables 4 and 5, Fig. 9).

In regard to two last-mentioned points, the conclusions drawn by Nersten (1967, p. 424) were the opposite. This may in part arise from the various sizes of areas discussed: Nersten was concerned with 1 to 100 sq.km. and here it is a matter of from 0.5 to 2 sq.km. only.

An increasing mean volume seems to result in a somewhat smaller plot size (Tables 4 and 5). However, if the precision is given in terms of cubic metres per area unit, the increased mean volume implies a larger plot size (Fig. 10).

A comparison of the times listed in the upper and lower halves of Tables 4 and 5 indicates that much more survey time is required for the same mean and total volume, but a larger total area and a smaller forest percentage. Accurate determination of the tree-bearing area may provide a good means for improvement of the efficiency of an inventory (cf. p. 14).

Tables 4 and 5 indicate that the time requirement is diminished roughly to 50 per cent when the standard error is doubled. If

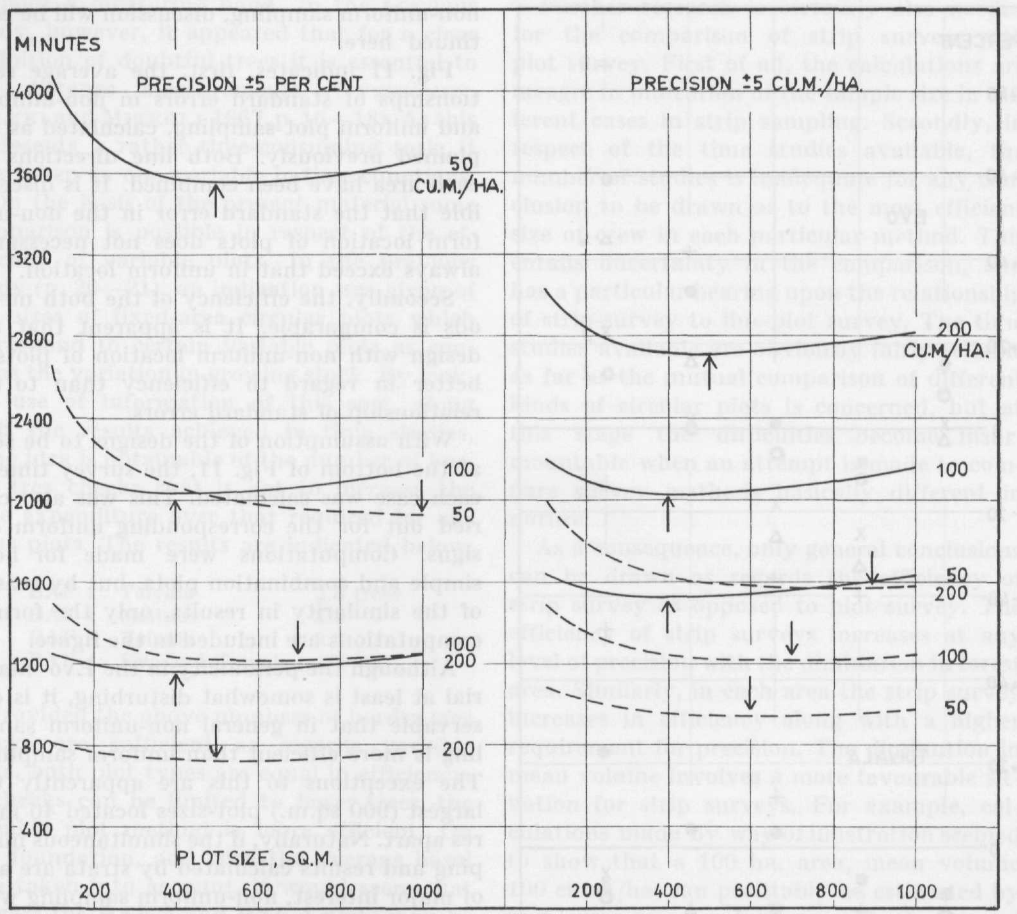

Fig. 10. Survey time as a function of size of combination plots, without sample tree and fixed times. Evo tree numbers, forest percentage 100, clearing time 4 min./plot. Solid lines: area 200 ha.; broken lines: area 50 ha. Optimum plot sizes indicated by arrows.

Kuva 10. Arviointiaika (ilman kiinteää ja koepuuaikaa) koealan suuruuden funktiona luettaessa vain suuret puut koko koealalta. Evon runkoluvut, puustoista alaa 100 %, valmisteluaika 4 min/koeala. Yhtäjaksoiset viivat: ala 200 ha; katkoviivat: ala 50 ha. Optimisuuruudet osoitettu nuolilla.

attention is also paid to the fixed time and sample tree time of field work, and the cost of computation, the reduction in inventory costs is essentially less than what might be expected from a more theoretical discussion of the problem (cf. NERSTEN 1967, p. 417).

An opportunity to draw some other conclusions in regard to the times needed is provided by Tables 4 and 5. For instance, some conception is obtainable of the increase in time requirement in an inventory of increasing growing stock, if the aim is attainment of the same precision in cubic metres; in a given case, for example, the precision percentage of ± 10 for mean volume 50, ± 5 for 100, and ± 2.5 for 200 cu.m./ha.

42. Non-uniform plot sampling

Non-uniform systematic plot sampling implies a method in which the plots are placed more closely to each other along the lines than the distance between the lines. In the earlier paper, some comparisons were made in regard to the method (NYSSÖNEN, KILKKI and MIKKOLA 1967, p. 50—52). By virtue of the great importance of the application of

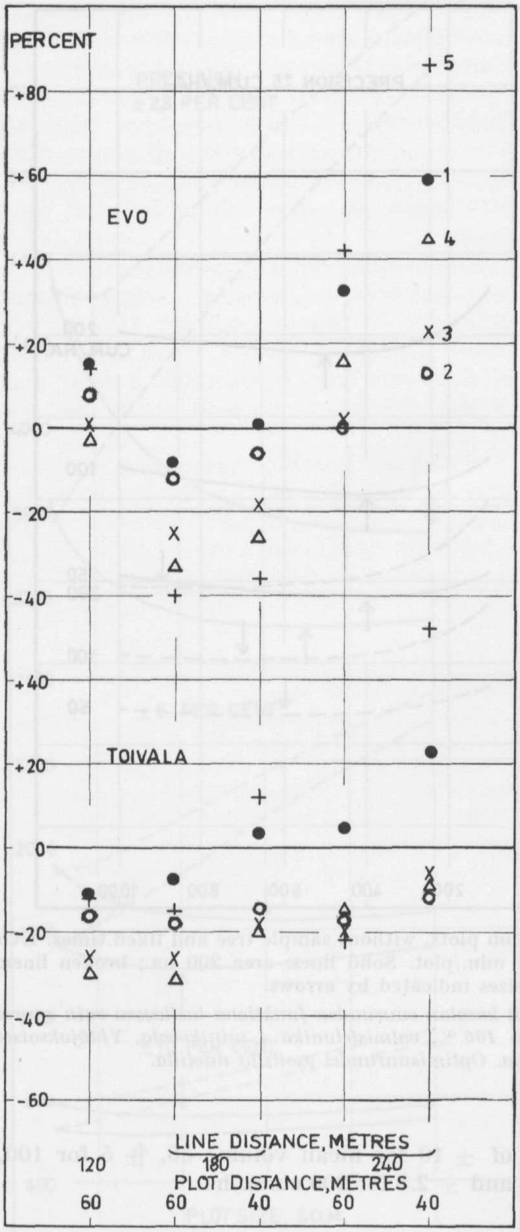

Fig. 11. Comparison of uniform and non-uniform systematic plot sampling, simple plots. Indications are given of the percentages by which the standard errors and survey times respectively of non-uniform sampling are less or more than those of uniform sampling for the same plot number, area and mean volume.

Standard errors, all plot sizes: No. 1
Survey times: No. 2 100 sq.m. plots
» 3 200 » »
» 4 400 » »
» 5 900 » »

non-uniform sampling, discussion will be continued here.

Fig. 11 indicates, first, the average relationships of standard errors in non-uniform and uniform plot sampling, calculated as explained previously. Both line directions on each area have been combined. It is discernible that the standard error in the non-uniform location of plots does not necessarily always exceed that in uniform location.

Secondly, the efficiency of the both methods is comparable. It is apparent that the design with non-uniform location of plots is better in regard to efficiency than to the relationship of standard errors.

With assumption of the designs to be seen at the bottom of Fig. 11, the survey time in each case was calculated. This was also carried out for the corresponding uniform designs. Computations were made for both simple and combination plots, but by reason of the similarity in results, only the former computations are included in the figure.

Although the periodicity in the Evo material at least is somewhat disturbing, it is observable that in general non-uniform sampling is more efficient than uniform sampling. The exceptions to this are apparently the largest (900 sq.m.) plot-sizes located 40 metres apart. Naturally, if the simultaneous mapping and results calculated by strata are also of major interest, non-uniform sampling with very small relationship between plot interval and line distance may not provide a satisfactory alternative.

With regard to the plot size, one may be inclined to say that non-uniform sampling inherently applies to smaller plots than does uniform sampling, but Fig. 11 does not warrant clear conclusions in this respect. In any event, non-uniform sampling, especially as concerns larger areas, calls for further studies.

43. Strips and variable plots as opposed to circular plots

On the combination plots discussed previously, large-sized trees are tallied on concentric circles from a larger area than are small-sized ones. Plots of this type were found rather efficient. The same idea, in a more flexible form, is inherent in variable plots, in which moreover the trees to be included may be marked without a measuring band. In the previous study, however, it appeared that for a clear definition of doubtful trees it is essential to use distance measurements (NYYSSÖNEN, KILKKI and MIKKOLA 1967, p. 16—18). As this represents a rather time-consuming task, it was taken as one variable in time equations.

On the basis of the present material some comparison is possible in respect of the efficiency of variable plots. In the previous study (p. 20—21), an indication was given of the sizes of fixed-area circular plots which correspond to certain variable plots as concerns the variation in growing stock. By making use of information of this sort, along with the results achieved in time studies, some idea is obtainable of the number of border tree checks that is apt to increase the time expenditure over that required for circular plots. The results are indicated below:

BAF 1	Toivala	2.8 trees
BAF 1	Meltaus	2.2 »
BAF 2	Toivala	2.2 »
BAF 4	Evo and Toivala	1.6 »

Provided the above numbers of border tree checks are sufficient as regards variable plots, both plot types are equal in efficiency. If checks can be limited to fewer trees, the variable plot method is more efficient. On this foundation, and with the average basal area taken into account, it would seem that at least the BAF 2 and BAF 4 plots may be more efficient than the simple circular plots. However, further comparisons are needed to provide a clearer picture of these internal relationships; this is particularly the case in that combination plots appeared superior to simple ones.

Further research is certainly also needed for the comparison of strip survey with plot survey. First of all, the calculations are meagre in indication of the sample size in different cases in strip sampling. Secondly, in respect of the time studies available, the number of studies is inadequate for any conclusion to be drawn as to the most efficient size of crew in each particular method. This entails uncertainty in the comparison, and has a particular bearing upon the relationship of strip-survey to line-plot survey. The time studies available are obviously fairly reliable as far as the mutual comparison of different kinds of circular plots is concerned, but at this stage the difficulties become insurmountable when an attempt is made to compare survey methods basically different in nature.

As a consequence, only general conclusions can be drawn as regards the efficiency of strip survey as opposed to plot survey. The efficiency of strip surveys increases at any level of precision with the diminution in forest area. Similarly, in each area the strip survey increases in efficiency along with a higher requirement for precision. The diminution in mean volume involves a more favourable situation for strip surveys. For example, calculations made by way of illustration seemed to show that a 100 ha. area, mean volume 100 cu.m./ha, can profitably be estimated by plot survey, assuming a standard error of $\pm$ 5 per cent, while it would be doubtful with $\pm$ 2.5 percent error as target. In any case, earlier opinions expressed in regard to the efficiency of both methods may need correction (cf. HAGBERG 1958).

5. SUMMARY AND CONCLUSIONS

This paper, which is continuation of an earlier publication by NYYSSÖNEN, KILKKI and MIKKOLA (1967), summarizes studies on the efficiency of forest inventory methods which extended over several years. While an analysis, based upon the detailed measurement of one 100 hectare forest was made previously, another area of the same size was measured for the present study, to enable extension of the scope of application.

On comparison of different sampling methods, it was found that additional information on strata areas, obtainable from maps or survey lines, improves the precision of an inventory. For approximate estimation of the standard error in simple systematic surveys from a sample, the method of stratified random surveys might be applied. However, special emphasis was laid on the finding of regression equations to indicate the dependence of standard error upon various variables in systematic sampling. As a result, the size of sample for a given precision could be computed, under varying alternatives of sample plot size and type. In addition to simple plots, on which all the trees were tallied, combination plots were included; on these, it is assumed that trees of different sizes are tallied on concentric circles (D.B.H. less than 10 cm. on an area of 25 sq.m., between 10 and 20 cm. on 100 sq.m., and more than 20 cm. on a given larger area).

Another major task was that of examining inventory costs by means of time studies. Attention was paid to the time requirements at the various phases of work. The time expenditure, both under experimental conditions and in practical inventory, was taken as a basis.

On combination of the results in regard to the sample size and survey time, the relative efficiency of different alternatives could be discussed, with a view to the precision of the total volume of growing stock. It appeared that combination plots were more efficient than simple plots. The common optimum for the former was 400 to 500 sq.m., and that for the latter 200 sq.m., or even less. In general, a reasonable deviation from the optimum does not mean an essential difference in the time expenditure.

An accurate determination of tree-bearing area often provides a good means for improvement of the efficiency of an inventory. The increase in requirement for precision does not as a rule involve such an increase in the inventory cost as that, for instance, in the sample-plot number.

A few statements are made in regard to other designs, in addition to the simple uniform plot sampling referred to above. As a rule, the non-uniform location of plots (i.e., plots placed closer to each other along the lines than the distance between the lines) results in a more efficient procedure than does the uniform type. In view of the need to check the inclusion or exclusion of doubtful trees on variable plots, further comparisons are necessary to demonstrate the internal efficiency of the use of these and fixed-area plots. This is also true of strip survey.

In the following, some restrictions in application of the results are mentioned. Although the size class of test areas measured here is rather important in Finnish circumstances, they are relatively small, and cannot indicate overall trends, such as in sample-plot size. Time studies have some inherent deficiency: optimum procedures and crew sizes for different tasks have not been studied in great detail. Furthermore, discussion here relates to sampling error alone. Additionally, serious attention is due to the possibility of deviations with sources of origin that include: deficiency of volume tables, inaccuracy in measurement, and faulty location of sample plot centres.

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SELOSTE:

SYSTEMAATTISEEN OTANTAAN PERUSTUVAN METSÄN INVENTOINNIN TEHOKKUUDESTA

Tutkimuksessa, joka on jatkoa aiemmalle NYYSSÖSEN, KILKIN ja MIKKOLAN (1967) julkaisulle, on kysymys pitkäaikaisten töiden päätuloksista. Ominaista työlle on se, että metsässä yksityiskohtaisesti ruuduittain mitatusta aineistosta on tietokonetta käyttäen poimittu lukuisia otoksia, joiden perusteella on voitu laskea näytteen suuruus eri tapauksissa. Aikatutkimusten avulla on voitu verrata eri vaihtoehtojen tehokkuutta.

Aiempi tutkimus nojasi pääosin yhteen 100 hehtaarin alueeseen. Tulosten yleistämiskelpoisuuden parantamiseksi mitattiin toinen samansuuruinen alue, ja tämän tutkimuksen sisältö on tulosta molempien alueiden analysoinnista. Jatkettaessa otantamenetelmien vertailua kävi muun muassa selville, että näyteyksiköiden systemaattiseen sijoitukseen perustuvan menetelmän keskivirheestä voidaan usein saada likimääräinen käsitys käyttämällä luokitetun satunnaisvalinnan virheenlaskentakaavoja. Metsikköluokkien pinta-aloista joko kartalta tai arviointilinjoilta saatava lisätieto pienentää inventoinnin keskivirhettä.

Erityisenä tavoitteena oli kehittää regressioyhtälöitä systemaattisten koeala-arviointien luotettavuuden selvittämiseksi. Yhtälöitä käyttäen on mahdollista laskea tietyn keskivirheen edellyttämä näytteen suuruus eri koealatyyppejä käytettäessä (esim. taulukko 2 s. 13). Paitsi kaikkien puiden läpimitan selvitystä vaativia koealoja käsiteltiin sellaisia yhdistelmäkoealoja, joilla suuret puut luetaan isommalta alalta kuin pienet: rinnantasalta alle 10 cm puut 25 m², 10–20 cm puut 100 m² ja yli 20 cm puut koko alalta.

Toinen laaja tehtävä tutkimuksessa oli inventointikustannusten selvittäminen aikatutkimusten avulla. Huomiota kiinnitettiin eri työvaiheiden vaatimaan aikaan. Perustana oli ajanmenekki sekä koeolosuhteissa että käytännön inventoinnissa. Taulukosta 3 (s. 17) nähdään esim. erilaisten koealojen rajoituksen ja puiden luvun vaatima keskimääräinen aika.

Yhdistämällä otoksen suuruutta ja arviointiaikaa koskevat tulokset voitiin tarkastella eri vaihtoehtojen tehokkuutta pidettäessä tavoitteena puuston kokonaiskuutiomäärän arviointitarkkuutta. Yhdistelmäkoealojen yleiseksi optimikooksi tuli 4–5 aaria. Ne osoittautuivat tehokkaammiksi kuin kaikkien puiden lukua edellyttävät koealat, joiden optimisuuruus taas oli 2 aaria tai allekin. Kohtuullinen poikkeama optimista ei yleensä merkitse tuntuvasti suurempaa ajankäyttöä. Taulukoista 4 ja 5 (s. 18 ja 19) sekä kuvista 9 ja 10 (s. 20 ja 21) nähdään lähempiä piirteitä arviointiajasta. Kiinteä aika sekä koepuuaika on jätetty tarkastelun ulkopuolelle, koska ne eivät vaikuta toisiaan vastaavissa tapauksissa eri vaihtoehtojen keskinäiseen järjestykseen.

Puustoisen alan luotettava määrittäminen on usein hyvä keino inventoinnin tehokkuuden parantamiseksi. Tulosten luotettavuusasteen nostaminen ei yleensä näytä kohottavan arviointikustannuksia samassa suhteessa kuin esim. koealalukua.

Edellä esitetyt päätelmät koskevat lähinnä sellaisia koeala-arviointeja, joilla näytealat sijaitsevat molemmissa suunnissa samalla etäisyydellä toisistaan. Koealojen sijoittaminen linjoille lyhemmin välimatkoin kuin linjavälin päähän toisistaan merkitsee yleensä suurempaa tehokkuutta kokonaiskuutiomäärän arvioinnissa. Relaskooppikoealojen ja kiinteäalaisten koealojen keskinäinen vertailu edellyttää vielä jatkotutkimuksia epävarmojen ja siten tarkistusta kaipaavien rajapuiden lukumäärästä relaskooppialoilla, mutta ainakin suurehkoja tähtäyskulmia käytettäessä niillä lienee mahdollista selviytyä vähemmällä ajalla kuin vastaavia kiinteäalaisia koealoja sovellettaessa.

Kaista-arvioinnin tehokkuus kasvaa koeala-arvioinnin tehokkuuteen verrattuna seuraavissa tapauksissa: metsän pinta-ala tai keskikuutiomäärä pienenee taikka arvioinnin tarkkuusvaatimus kasvaa. Esimerkin vuoksi tehdyt laskelmat osoittivat, että pinta-alan ollessa 100 ha ja keskikuutiomäärän 100 m^3/ha alue kannattaa arvioida koeala-arvioinnilla, mikäli tavoitteena on $\pm$ 5 % keskivirhe, mutta kaista-arvioinnilla, kun tähdätään $\pm$ 2.5 % keskivirheeseen.

Tulosten soveltamisessa on pidettävä mielessä tiettyjä rajoituksia. Vaikka nyt tutkittujen koealueiden suuruusluokka, 100 ha, on tärkeä Suomen oloissa, ne eivät voi riittävästi kuvata esim. koealan suuruuskysymyksen yleisiä trendejä. Aikatutkimuksilla on omat puutteensa, sillä työmenetelmiä ja työryhmän optimisuuruutta ei ole voitu perusteellisesti selvittää. Hyvin tärkeää on lisäksi huomata, että tutkimuksessa on käsitelty vain otantavirhettä. Arviointia suunniteltaessa on sen lisäksi kiinnitettävä huomiota mm. siihen virhevarianssiin, joka aiheutuu kuutioimistaulukoiden käytöstä, mittausvirheistä sekä koealojen paikallistamisesta.

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SUOMEN PUUNJALOSTUSTEOLLISUUDEN KESKUSLIITTO

OSUUSKUNTA METSÄLIITTO

KESKUSOSUUSLIIKE HANKKIJA

SUNILA OSAKEYHTIÖ

OY WILH. SCHAUMAN AB

OY KAUKAS AB

RIKKIHAPPO OY

G. A. SERLACHIUS OY

TYPPI OY

KYMIN OSAKEYHTIÖ

SUOMALAISEN KIRJALLISUUDEN KIRJAPAINO

UUDENMAAN KIRJAPAINO OSAKEYHTIÖ

KESKUSMETSÄLAUTAKUNTA TAPIO

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OY TAMPELLA AB

JOUTSENO-PULP OSAKEYHTIÖ

TUKKIKESKUS

KEMI OY

MAATALOUSTUOTTAJAIN KESKUSLIITTO

VAKUUTUSOSAKEYHTIÖ POHJOLA

VEITSILUOTO OSAKEYHTIÖ

OSUUSPANKKIEN KESKUSPANKKI OY

SUOMEN SAHANOMISTAJAYHDISTYS

OY HACKMAN AB

YHTYNEET PAPERITEHTAAT OSAKEYHTIÖ