THE EFFECT OF STRATIFICATION ON THE NUMBER OF SAMPLE PLOTS OF DIFFERENT SIZES

AARNE NYYSSÖNEN AND YRJÖ VUOKILA

SELOSTUS:

METSIKÖIDEN LUOKITUKSEN VAIKUTUS ERISUURUISTEN KOEALOJEN LUKUMÄÄRÄÄN

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1. Introduction

Only a few investigations have been reported and instructions issued with regard to the number and the most efficient size of sample plots in forest inventories under Finnish conditions.

In 1935, ILVESSALO discussed the size of sample plots. He compared line-plot surveys of rather small forests, found that circular plots of 200 sq.m. were the most efficient, but finally recommended the use of 300 sq.m. plots. In national forest inventories, where sample plots were used for checking and correcting ocular estimation of the volume and increment of the growing stock, much larger plots have been utilised, generally speaking ones with an area of 1000 sq.m. (cf. ILVESSALO 1936). Nevertheless, there was an observable trend towards larger sample plots during the 1940's and 1950's in many other instances. Thus, for saw-timber trees, circular plots of 500—1000 sq.m. were often recommended (e.g. OSARA 1948; ILVESSALO 1956). It may be pointed out that in the cases referred to above smaller trees (D.B.H. not more than 10 cm.) were in general çalipered on 100 sq.m. plots.

The recommendations mentioned above were not observed when a large timber company (Enso-Gutzeit . . .), following Swedish examples, employed small sample plots, 138 sq.m. in size, in a forest inventory in 1958—59. KANGAS (1959—1960) was in favour of 100 to 200 sq.m. plots in his study for determining the drain in the state forests. For Scotch pine forests in northernmost Finland, KUUSELA (1960a) found 400 sq.m. plots to be satisfactory, and recommended for marked timber the application of 300 sq.m. plots in the south of the country and 500 sq.m. plots in the north (KUUSELA 1960b). In the fourth national forest inventory, started in 1960, the size of sample plots has been reduced to 300 sq.m; the ocular estimation of volume and growth no longer forms a part of this undertaking.

As for other investigations carried out under conditions comparable with those which prevail in Finland, the studies connected with the Swedish national forest inventory (Vid andra . . .; HAGBERG 1957) resulted in the above-mentioned application of 138 sq.m. sample plots. In Norway, 200 sq.m. plots are in fairly general use (e.g. STRIDSBERG 1956); however, in the national forest inventory the plot size is 100 sq.m. (Taksering . . . 1961). STRAND (1957) there concluded that the variation range of sample plots of similar efficiency is wide, but he also estimated that the most efficient size of sample plots under Norwegian conditions cannot appreciably exceed 100 sq.m. In Germany, PRODAN (1955, 1958) preferred the application of 1000 sq.m. plots, and RICHTER and GROSSMANN (1959) considered 300 sq.m. (for small trees 50 sq.m.) to be most advantageous.

Of course, in any consideration of the number of sample plots, their size must always be borne in mind. However, the number of sample plots has been studied less than has their size.

In the investigation previously quoted, ILVESSALO (1935) studied also the number of plots. Subsequently (1959), he issued instructions on the distances between lines and plots, although the degree of accuracy obtainable by this means was not mentioned. OSARA (1948) published corresponding figures. Further to this, KUUSELA (1960b) presented guiding figures for estimating marked timber, on the assumption that the error of the mean would not exceed ± 10 per cent with a probability of 95 per cent. In addition, there are numerous publications from other countries which contain guidance in this respect (Anvisningar . . . 1952; HAGBERG 1958; RICHTER and GROSSMANN 1959).

The investigations cited have yielded results which deviate considerably from each other, both in the size and the number of sample plots. This is to be expected in view of the wide variations in the purpose of the inventories, the diversity of the growing stock and the cost factors involved. But even when the prerequisites have been similar, the sizes of sample plots have varied substantially. When the investigation findings are scrutinised in order to provide information for inventories which range from some tens to some thousands of hectares, no conclusive guidance is apparent. The importance of stratification frequently dealt with in foreign investigations starting from the early 1950's (e.g. BICKFORD 1952, 1961; STRAND 1957) was only lately touched upon in Finnish papers (KUUSELA 1960a; NYYSSÖNEN 1961; NYYSSÖNEN and POSO 1962.)

For these reasons, it is necessary to study the problems relating to the size, number and location of sample plots as well as to the effect of stratification. This paper, which is mainly concerned with the volume of the growing stock based upon detailed measurements, comprises a part of the research work currently in progress.

This study was started by the authors in the Forest Inventory Section of the Forest Research Institute — Prof. YRJÖ ILVESSALO as Section Chief — and was completed in the Institute of Forest Mensuration and Management of the University of Helsinki.

2. Collection and Treatment of the Research Material

Two experimental areas, approximately 10 hectares each, were chosen in the south of Finland between 25° and 26° E. long. and between 60° and 61° N. lat. One of them is located in the Experimental Forest of Ruotsinkylä, and the other in a farm forest in Orimattila. In the selection of these areas, particular

regard was given to as wide a representation as possible of the different tree species and the different classes of stand development and forest sites. The Scotch pine and the Norway spruce dominate in these forests. These rectangular areas include 45 stands or portions of them, mostly of natural origin, which have been subjected to satisfactory or good silvicultural treatment. In the calculations, the total area of 20 ha. was treated as a unit.

During the field work in 1957, the experimental areas were divided into 7 metre squares (49 sq.m.). Thus the total number of squares was c. 4000. In every square there was measured separately the D.B.H. of each tree. The height and taper required for the tree volume tables of ILVESSALO (1947) were measured in every third or fourth square throughout the whole area. In addition, there was registered the basic information for each stand.

The treatment of the material was initiated by drawing height and taper curves for each stand, to obtain the unit volumes by classes of D.B.H. By means of tree numbers, there was found the cubic volume of each square; the calculation procedure used meant that these volumes were adjusted to a certain extent. By combining adjacent squares, it was possible to calculate volumes for multiple areas up to 784 sq.m. Subsequently, it was possible to determine the mean volumes, standard deviations and coefficients of variation for each plot size within the forest area as a whole and within certain strata.

The method of classification of stands, stratification, used in the present study is mainly based upon the dominant height, and is accordingly of especial value in classifications from aerial photographs. The dominant height was calculated as the mean height of the 100 largest trees in diameter per ha. In addition to the three strata which represented fully-stocked stands, the fourth stratum referred to more open stands, those treated with preparatory cuttings for regeneration. As a whole, the strata were as follows:

Stratum	1	Dominant height not more than 11.0 metres
»	2	Dominant height 11.1 to 19.0 metres
»	3	Dominant height not less than 19.1 metres
»	4	Stands treated with preparatory cuttings; dominant height not less than 18.0 metres

The mean $\bar{x}$, the standard deviation s, and the coefficient of variation V were arrived at by means of the following formulae:

$$\bar{x} = \frac{\Sigma x}{n}$$

$$s = \sqrt{\frac{\Sigma x^2 - (\Sigma x)^2/n}{n - 1}}$$

$$V = \frac{100s}{\bar{x}}$$

where $x =$ the volume per ha. of the plot and $n =$ number of plots. Additional formulae applied in the calculations are presented below.

Since the 49 sq.m. plots often contained zero volumes in strata 3 and 4, the standard deviations and factors based upon them are later given only for strata 1 and 2 as regard this size of plot.

In order to arrive at results which are applicable to a certain kind of desirable growing stock, it was assumed that Stratum 1 represented young stands, Stratum 2 stands in the thinning stage, Stratum 3 stands mature for regeneration, and Stratum 4 stands treated with preparatory and shelter-wood cuttings. On this basis, in calculations relating to forest areas as a whole, the following proportions of the different strata, which deviate somewhat from those encountered within the experimental areas, were applied:

Non-forested	10 per cent
Stratum 1	20 »
» 2	30 »
» 3	20 »
» 4	20 »

Moreover, one important consideration is that the calculated numbers of sample plots refer consistently to an error of the mean of $\pm$ 10 per cent, with a probability of 95 per cent, i.e. the single standard error is 5 per cent of the mean.

The results will be presented in two main parts. No stratification has been applied in the calculations detailed in Chapter 3, but this has been effected in Chapter 4.

3. The Forest Area as a Whole

31. Standard Deviations and Coefficients of Variation

If we assume the proportions of the different strata to correspond to those given earlier, the mean volume of the present material is 102 cu.m. per ha., including bark. The following standard deviations and coefficients of variation are obtained for different sizes of plots:

Plot size	98	196	392	784 sq.m.
s	77	69	63	60 cu.m./ha.
V	75	68	62	59 per cent

At this stage, it can already be noticed that the coefficient of variation decreases relatively slowly with increasing plot size.

32. Number of Sample Plots

The number of sample plots required was calculated assuming the variation given in Chapter 31 and random sampling. Although the study of variation has been based on two forest areas totalling 20 ha. only, the plot numbers have also been calculated for a forest area of 100 ha. The correction necessitated by the small size of the population is taken into account by application of the following formula (cf. Manual . . . 1960):

$$n = \frac{t^2s^2}{E^2 + \frac{t^2s^2}{N}}$$

where the symbols not previously mentioned are:

E = allowable error
t = normal deviate, the value of which measures the probability that the error will not exceed that allowable; here t = 2 with the probability of 95 per cent that the error E will not be exceeded
N = total number of possible sample units

On this basis, the numbers of sample plots are as follows:

Plot size	98	196	392	784 sq.m.
20 ha.	205	155	117	90 plots
100 »	223	177	144	125 »

This set-up gives numbers which seem rather large. They decrease to approximately one half when the size of the sample plot is enlarged 8 times. If a similar degree of accuracy is aimed at, the largest sample plots necessitate a tree count over a total area 4 times the size of that covered by the smallest ones. If the tree count constitutes a substantial proportion of the total time and expense entailed in the inventory, then relatively small sample plots should be used in surveys of unstratified forest areas.

When the variation within forest areas of different size is assumed to be the same, then to cruise 100 ha. of forest 18 to 35 more sample plots are needed than for the 20 ha. area. For example, when surveying an area of 1000 ha., 4 to 12 sample plots are necessary in addition to those required by the 100 ha. area. In general, however, the variation presumably increases with the expansion of the forest area, and the number of sample plots required increases more rapidly than is indicated above.

4. The Forest Area Stratified

41. Standard Deviations and Coefficients of Variation

Standard deviations by strata are as follows:

Plot size	49	98	196	392	784 sq.m.
Stratum 1	31	27	26	20	19 cu.m./ha
» 2	60	47	38	32	30 »
» 3	—	78	62	50	42 »
» 4	—	68	53	40	32 »

Mean volumes by strata are the following:

Stratum	1	54 cu.m./ha
»	2	118 »
»	3	190 »
»	4	88 »

Consequently, the coefficients of variation are:

Plot size		49	98	196	392	784 sq.m.
Stratum	1	57	50	48	37	35 per cent
»	2	51	40	32	27	25 »
»	3	—	41	33	26	22 »
»	4	—	77	60	45	36 »

The standard deviations of strata 1 and 2 are considerably smaller than those of strata 3 and 4. When the aim is an accuracy expressed in cubic metres, fewer sample plots are needed in stands of an early stage of development than in those belonging to more advanced stages. But as a rule the relative variation diminishes as a function of an increasing volume, as has already been pointed out (e.g. LANGSAETER 1932). Furthermore, it seems likely that, with the same cubic volume and the use of small sample plots, the variation increases with the increasing size of trees. Stands in the thinning stage (Stratum 2) are rather homogeneous and require relatively few sample plots, although the volume of the growing stock may not be high.

When the above coefficients of variation are compared with those presented in Chapter 31 (p. 8) for the forest area as a whole, it can be noticed that with but one exception the former coefficients are smaller than the latter ones. The effect exerted by this on the number of sample plots and some other relevant considerations are discussed in the following chapter.

42. Number of Sample Plots

421. Within Strata

Only in rather exceptional instances does a forest area comprise a single stratum. Nevertheless, interest is attached to calculation of the number of sample plots on this assumption, with the same prerequisites as those stated in Chapter 32. The following figures refer to a forest area of 100 ha:

Plot size		49	98	196	392	784 sq.m.
Stratum	1	131	99	91	54	48 plots
»	2	103	63	41	29	25 »
»	3	—	67	42	27	19 »
»	4	—	233	141	80	51 »

Of course, in surveying the cubic volume of a single stratum, fewer sample plots are required than in cruising a forest area in which several strata are represented. Acccordingly, although on p. 9 the number of 196 sq.m. sample plots was given as 177, the present set-up shows that about one half of it is needed for Stratum 1, less than a quarter for strata 2 and 3, and four fifths for Stratum 4.

The number of sample plots required for the different strata decreases more markedly with the increasing size of plots than in an unstratified forest area (cf. the set-up on p. 9). Whereas a multiplication of 98 sq.m. plots by 8 reduced the plot number to 56 per cent in unstratified forest areas, the corresponding percentages for strata 1 to 4 are as follows: 48, 40, 28, and 22. This confirms the statement of STRAND (1957): the more homogeneous the material and the more detailed the stratification, the larger should be the sample plots. Attention may also be paid to bigger sample plots being more efficient in large-sized timber, such as those represented by Stratum 3 and particularly Stratum 4. This favours the use of the relascope and those methods on circular sample plots which involve the counting of bigger trees over a larger area than the smaller ones, which has in fact already taken place to a certain extent in practical inventories.

422. Within the Forest Area

As regards the accuracy of the results the proportion of the different strata (p. 8), and the variation within the strata (p. 10), the calculations concerning the forest area are based upon the prerequisites stated earlier. Further to this, the determination of sample size demands certain assumptions on the distribution of field plots among the strata. In this investigation, two different assumptions were made for the calculations: 1. optimum allocation, and 2. proportional allocation (cf. Manual . . . 1960, pp. 486—487).

Optimum allocation presupposes that the sample plots are distributed among the strata in relation to the products of their areas and standard deviations. This method of distributing field plots gives the minimum error of volume estimate for a given number of field plots. The number of sample plots can be calculated by means of equation

$$n = \frac{t^2 (\Sigma P_i S_i)^2}{E^2 + \frac{t^2 \Sigma P_i S_i^2}{N}}$$

where the symbols not previously given are

P_i = the proportion of the area in the ith class, and
S_i = the standard deviation in that class.

The equation gives the following number of plots:

Plot size	98	196	392	784 sq.m.
20 ha.	86	56	35	26 plots
100 »	90	59	38	29 »

Comparison of these figures with the numbers of sample plots in an unstratified area (p. 8) indicates that considerably fewer sample plots are now required. For instance, the number now given for the forest area of 100 ha. is only 40 per cent of the previous one for the 98 sq.m. plots, and 23 per cent of that for the 784 sq.m. plots. By the application of stratification, the larger sample plots prove relatively more efficient, as has already been pointed out. However, since the 784 sq.m. plots presuppose a tree count over an area 1.5 times the size of that required for sample plots of 392 sq.m., it is hardly remunerative to enlarge the plot size excessively.

Proportional allocation distributes the sample plots among the different strata in relation to their areas. The number of sample plots is calculated by means of the following equation:

$$n = \frac{t^2 \Sigma P_i S_i^2}{E^2 + \frac{t^2 \Sigma P_i S_i^2}{N}}$$

which gives, with the present prerequisites, the following results:

Plot size	98	196	392	784 sq.m.
20 ha.	107	68	43	30 plots
100 »	112	72	46	34 »

The plot numbers obtained do not much exceed those calculated with the optimum allocation. Since the plot numbers for tree-growing strata in the proportional allocation are 10 per cent less than in the set-up, the numbers of sample plots to be actually measured are here only slightly greater than those obtained for the optimum allocation. It is noticeable that the practical application of proportional allocation is simpler and easier than that of optimum allocation.

5. Summary and Conclusions

This study contains a discussion of certain problems relevant to the planning of a forest inventory on the basis of variation in the growing-stock volume. In particular, the aim has been that of giving data for the selection of the size and number of sample plots, and providing an illustration of the importance of stratification, here based principally on the dominant height.

The research material comprised two forest areas of 10 ha. each; measurement of the growing stock was made in units of 49 sq.m. The results have been used

as a basis for the construction of a model area embracing 4 forested strata and one non-forested stratum. The means and standard deviations of the volumes have been calculated for the forest area as a whole, and for the different strata using sample plot sizes varying in certain cases from 49 sq.m., but more generally from 98 sq.m. to 784 sq.m. It has also been possible to determine the numbers of sample plots needed to cruise forest areas of 20 and 100 ha., assuming the random location of plots and an accuracy of $\pm$ 10 per cent with a probability of 95 per cent.

As regards the forest area as a whole, i.e. without stratification, attention may be directed to the large numbers of sample plots, considerably exceeding those given in certain Finnish survey instructions, which assume systematic sampling, however.

On studying stratification, two different approaches were employed to distribute sample plots among the strata: optimum allocation and proportional allocation. Proportional to area, the latter alternative is simple in application, and gave for forested areas numbers of sample plots which did not exceed by more than only 10 per cent those obtained by optimum allocation, which distributes the sample plots in proportion to the products of the areas and standard deviations of the different strata. This resulted in numbers which are 40 per cent for the 98 sq.m. plots, and for the 784 sq.m. plots only 23 per cent of those in an unstratified survey. It is accordingly rather obvious that the application of stratification is worthy of serious consideration within forest areas which comprise parts with distinct deviations from each other.

The decrease in the number of sample plots with increasing plot size is considerably more marked within a stratified area than within an unstratified one. Thus larger sample plots should be used in the former case than in the latter. Correspondingly, in stands which consist of bigger trees, larger sample plots are more efficient than is the case in younger stands. In practical inventories, the use of the relascope seems worth recommending; this also applies to those circular sample plot approaches which presuppose a count of bigger trees within a more extended radius than for smaller ones.

To sum up, the present paper gives important hints on how forest inventories should be carried out; but it has some serious limitations. In addition to the restricted scope and the onesidedness of the material, the lack of time studies must be accorded particular emphasis. The areas of the different strata have been presented as if free from error. Furthermore, the estimation of the standard deviation was effected in the usual way, which cannot be unreservedly applied to the systematic sampling common in forest inventories.

The arrangement of inventories as a whole demands many additional studies. In fact, a more comprehensive investigation of this kind is currently in progress at the Institute of Forest Mensuration and Management of the University of Helsinki.

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SELOSTUS:

METSIKÖIDEN LUOKITUKSEN VAIKUTUS ERISUURUISTEN KOEALOJEN LUKUMÄÄRÄÄN

Tässä tutkimuksessa on puuston kuutiomäärän vaihtelua tutkimalla pyritty selvittämään eräitä inventointien järjestämiseen liittyviä kysymyksiä. Erityisesti on ollut tarkoituksena saada pohjaa koealojen suuruuden ja lukumäärän valinnalle sekä valaista metsikköluokitusten merkitystä lähinnä valtapituuteen perustuvan jaottelun puitteissa.

Tutkimusaineiston muodostaa kaksi yhteensä noin 20 ha:n metsäaluetta, jotka sijaitsevat Tuusulassa ja Orimattilassa ja joiden puusto on mitattu käyttäen 49 m^2:n ruutuja pienimpinä yksikköinä. Mittaustuloksia on käytetty perustana koostettaessa metsä, jolla on erotettu 4 puustoisen metsän luokkaa ja yksi aukean maan luokka. Puuston kuutiomäärien keskiarvot ja keskihajonnat on voitu laskea koko metsäalueelle ja sen eri luokille eräissä tapauksissa 49 m^2:n, mutta yleensä 98 m^2:n ruuduista alkaen aina 784 m^2:n ruutuihin saakka (s. 8—10). Edelleen on ollut mahdollista, edellyttämällä umpimähkäisesti sijoitettuja koealoja ja 10 %:n tarkkuutta 95 %:n todennäköisyydellä, laskea tarvittavat koealamäärät 20 ja 100 ha:n alueille (s. 9, 12).

Metsäaluetta yhtenä kokonaisuutena, ts. ilman metsiköiden luokitusta käsiteltäessä kiinnittävät huomiota melko suuret koealaluvut, mitkä selvästi ylittävät suomalaisissa arvioimisohjeissa olevat lukumäärät, joita esitettäessä tosin on edellytetty systemaattista otantaa.

Metsikköluokituksia hyväksikäytettäessä on koealojen jakamisessa metsikköluokkiin käytetty kahta olettamusta: optimikiintiöinti ja suhteellinen kiintiöinti. Jälkimmäinen ollessaan suhteellinen pinta-alaan on yksinkertaisempi toteuttaa, mutta on puustoiselle metsämaalle antanut enintään vain noin 10 % suuremmat koealaluvut kuin pinta-alan ja keskihajonnan tulojen suhteessa koealat jakava optimikiintiöinti (vrt. s. 12). Tämä taas on antanut lukumäärät, mitkä 98 m^2:n koealoja käytettäessä ovat 40 % ja 784 m^2:n koealoille vastaavasti vain 23 % siitä, mikä on ollut tarpeen ilman metsiköiden luokitusta. Ilmeistä niin ollen on, että luokituksen käyttöä ansaitsee vakavasti harkita silloin, kun toisistaan selvästi poikkeavia osia metsäalueella on erotettavissa.

Tarkasteltaessa koealojen lukumäärän vähenemistä niiden koon suuretessa havaitaan sen olevan luokitetulla metsäalueella selvästi voimakkaampaa kuin luokittamattomalla. Edellisellä siis on paikallaan käyttää suurempia koealoja kuin jälkimmäisellä. Vastaavasti eri kehitysluokkia tarkasteltaessa havaitaan varttuneissa metsiköissä kaivattavan suurempia koealoja kuin nuorissa, niin kuin on luonnollista. Käytännön inventoinneissa näyttävät tarkoituksenmukaisilta relaskoopin käyttö sekä ympyräarvioinnissa menetelmät, jotka edellyttävät suurten puiden mittausta suuremmalla säteellä kuin pienten puiden lukemista.

Kaiken kaikkiaan on suoritetussa tutkimuksessa saatu tärkeitä viitteitä metsän inventointien järjestämiseksi. Kuitenkin on tutkimuksella huomattavat rajoituksensa. Tutkimusaineiston suppeuden ja siihen liittyvän yksipuolisuuden lisäksi on huomattava ennen muuta aikatutkimusten puuttuminen sekä se, että luokitetuilla metsäalueilla pinta-alat on edellytetty virheettömiksi. Edelleen on keskihajonnan estimointi suoritettu tavanomaisella tavalla, mikä ei kuitenkaan ilman muuta päde metsän inventoinnissa tavalliseen systemaattiseen valintaan nähden.

Inventointien järjestämistä kokonaisuutena ajateltaessa kaivataan siis jatkotutkimuksia useilla aloilla. Tällainen laajempi selvitys onkin parhaillaan käynnissä Helsingin yliopiston metsänarvioimistieteen laitoksessa.