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# Permanent sample plots in large-area forest inventory

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*TIIVISTELMÄ: PYSYVÄT KOEALAT SUURALUEIDEN INVENTOINNISSA*

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Theoretical and practical aspects of permanent sample plots are discussed in this paper. A study material of 6871 permanent sample plots was generated using increment sample plots of the 7th National Forest Inventory. The effect of measurement errors and use of increment functions as "a priori" information was studied via simulation experiments. The change in the growing stock volume between two consecutive measurement rounds was divided into the components drain, growth and mortality. Finally, a hypothetical inventory design using permanent sample plots was evaluated.

Tutkimuksessa on käsitelty pysyviin koealoihin perustuvan metsien inventoinnin teoreettisia ja käytännöllisiä näkökohtia. Valtakunnan metsien seitsemännen inventoinnin kasvukoealoista generoitiin 6871 pysyvän koealan tutkimusaineisto. Simulointikokeissa tutkittiin mm. mittausvirheitä ja kasvumallien ja -mittausten yhteiskäytön vaikutusta luotettavuustunnuksiin. Keskitilavuuden muutos kahden inventoinnin välisenä aikana jaettiin poistumaan, kasvuun ja luonnonpoistumaan, joiden luotettavuutta tarkasteltiin erikseen. Lopuksi on arvioitu erään pysyviin koealoihin perustuvan inventoinnin käyttökelpoisuutta.

Keywords: forest inventory, permanent sample plots, sampling.
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## 1. Introduction

The first forest inventories based on permanent sample plots were carried out in the Nordic countries in the late 1950's. Emphasis was placed in the inventories on estimating the growing stock volume, increment and drain (Ware and Cunia 1962, Nyyssönen 1967, 1972, 1981). The mean volume was calculated using the regression technique i.e. by updating the results of the previous inventory with the help of permanent sample plots, and then combining these data with the fresh data. The use of permanent plots reduced costs in estimating the change between two consecutive inventories.

The increased need for information about changes in the state of forests has aroused new interest in the use of permanent sample plots. Not only in estimation of the volume, volume increment and the change in the growing stock, but also in the measurement of the changes in the forest ecosystem and tree growth, data based on an objective sample are necessary. In Sweden, permanent sample plots were included in the national forest inventory for the first time in 1983 (Hägglund 1985). In Finland, the 8th national forest inventory (NFI) was started by establishing and measuring a network of 3 009 permanent sample plots, covering the whole country, in 1985–86 (Jukola-Sulonen et al. 1987). In the countries lying outside the temperate zone, such as China and Burma, permanent sample plots have also recently been used in forest inventories (Singh 1985).

The applicability of permanent sample plots in keeping forest resource information up to date is studied in the present paper.

A simulation study is carried out for this purpose, and an inventory design using permanent sample plots is evaluated.

# 2. The data

## 21. The data from the national forest inventory

In the 7th Finnish national forest inventory 21 treetally relascope sample plots were measured in each tract, four of which increments were measured. The data for the simulation study consisted of all 6 871 increment plots in Southern Finland. Stumps, dead trees, increment borings and height-increment measurements were used to determine the drain and state of the forests 5 years earlier. The increment of the trees was derived as the difference between the volumes on the two occasions. The volumes were calculated employing functions based on diameter at breast height and the height of the tree. The volume of the drain was obtained via a model based on stump diameter only. The increment of the drain was not taken into account in the calculations.

The generated sample plot data were considered to represent the measurements at the beginning and at the end of the 5-year period. The differences between the estimates obtained for growing stock volumes and increment and the NFI results for a corresponding area were relatively small. The estimate for the drain based on stump measurements was, however, considerably smaller than the drain statistics from other sources. This difference is probably due to errors both in stump tallying and in determining when felling took place. The drain figures in the data for this study were adjusted to the correct level by increasing the number of plots where, according to the inventory, logging had taken place within the last five years.

The plot means and standard deviations were as follows:

| | Mean $m^3/ha$ | Standard deviation $m^3/ha$ |
|---|---|---|
| Initial growing stock | 92 | 91 |
| Final growing stock | 98 | 91 |
| Increment/5 a | 21 | 17 |
| Drain/5 a | 15 | 47 |
| Mortality/5 a | 0,8 | 4 |

The correlation coefficient between the initial and final growing stocks on the plots was 0.81.

## 22. The data from the Nurmes Project

The data used in the time consumption studies was measured during the Nurmes



Project (Sevola 1983) in Northern Karelia. A total of 586 permanent sample plots, selected using a relascope, were established in 1980. 171 of them were remeasured in 1981 (Päivinen and Yli-Kojola 1982).

Three of the 21 sample plots on the NFI tract in Northern Karelia were marked as permanent plots. The distance between the permanent plots was 1 200–1 600 m. The centre of the plot was marked by inserting a small plastic tube into the ground. In addition to the normal inventory characteristics, the following measurements were made on the trees:

- $d_{1,3}$ in two directions at right angles to each other
- tree height
- $d_6$
- crown height
- location of the tree in terms of distance and direction from the plot centre.

When one third of the plots were remeasured one year after establishment, all the measurements except $d_6$ were repeated.

# 3. Reliability of the mean volume and mean volume change estimates

It is possible, using permanent sample plots, to reduce the probability that the random errors in the two successive inventories will be of opposite polarity. When permanent sample plots only are used in estimating change, the error variance of the change is:

$$s_{\bar{d}}^2 = \frac{s_1^2 + s_2^2 - 2rs_1s_2}{n_p} \qquad (1)$$

where $s_{\bar{d}}$ = standard error of the difference between the mean volumes
$s_1$ = standard deviation of the volume in the 1st inventory
$s_2$ = standard deviation of the volume in the 2nd inventory
$r$ = correlation coefficient for the 1st and 2nd measurement of volume on the sample plots
$n_p$ = number of the permanent sample plots.

If only part of the sample plots are permanent, $s_{\bar{d}}^2$ is derived as follows (Loetsch & Haller 1964, p. 270):

$$s_{\bar{d}}^2 = \frac{A^2s_1^2 + B^2s_2^2 - 2ABrs_1s_2}{n_p} + \frac{(1-A)^2s_1^2}{n_{bt}} + \frac{(1-B)^2s_2^2}{n_{at}} \qquad (2)$$

where $A = \frac{n_p(rn_{bt} + n_a)}{n_an_b - n_{at}n_{bt}r^2}$

$B = \frac{n_p(rn_{at} + n_b)}{n_an_b - n_{at}n_{bt}r^2}$

$n_a$ = number of all plots in 1st inventory
$n_b$ = number of all plots in 2nd inventory
$n_{at} = n_a - n_p$
$n_{bt} = n_b - n_p$

Figure 1 shows an example of the reliability of the mean volume change estimate

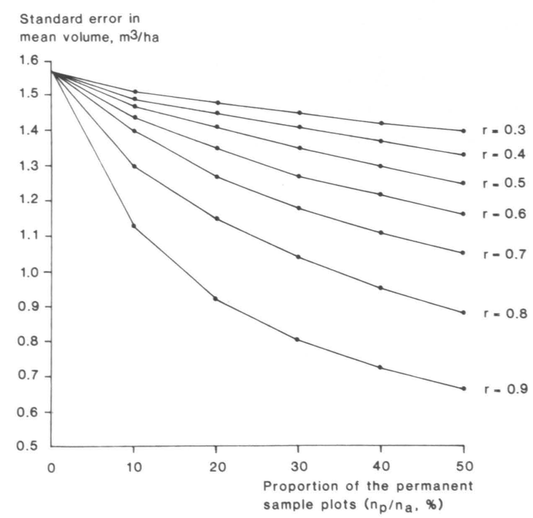


Fig. 1. The reliability of the estimate for the change in the mean volume as a function of remeasured plots.

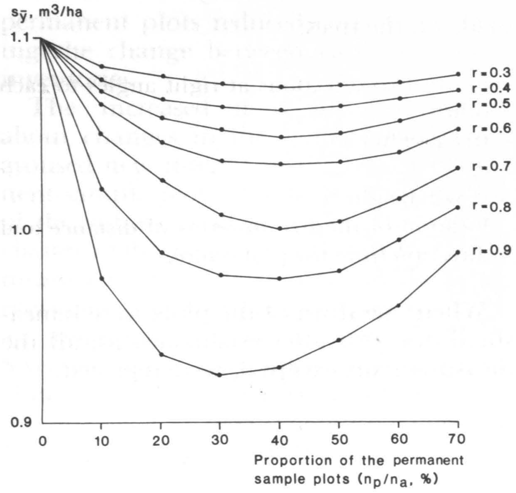


Fig. 2. The reliability of the growing stock estimate in an inventory based on permanent and temporary sample plots.

as a function of the correlation and proportion of the remeasured sample plots out of the total number of sample plots in the first measurement. The data used in the example are the NFI data described in the previous chapter. Thus $n_a = n_b = 6\,871$, $r = 0.81$, and $s_1 = s_2 = 91$ m³/ha.

The correlation coefficient is high in cases where the increment of the sample plots remains constant, and abrubt changes like logging do not occur. However, as the interval between iventories increases, the correlation usually tends to weaken. According to Nyyssönen (1981), the correlations between sample plot volumes in successive inventories in different studies are:

| Study area | Inventory interval, a | | | |
|---|---|---|---|---|
| | 5 | 6–7 | 10 | 16–17 |
| Enso-Gutzeit | | 0.69 | 0.65 | 0.39 |
| Rosenlew 1 | 0.78, 0.86 | | 0.65 | |
| Rosenlew 2 | 0.71 | | | |
| Serlachius | | | 0.72 | |

Planning of the national forest inventory in Sweden was based on the assumption that the correlation between sample plot volumes is 0.9 with an interval of 5 years (Hägglund 1985). The respective correlation in the Finnish national forest inventory data derived in this study is 0.81.

In addition to the permanent sample plots to be measured, the second inventory included the same number of new temporary sample plots as the first one.

The error variance of the mean volume estimate is

$$s_{\bar{y}}^2 = \frac{S_{\bar{y}r}^2 \, S_{\bar{y}t}^2}{S_{\bar{y}r}^2 + S_{\bar{y}t}^2} \qquad (3)$$

where $S_{\bar{y}r}^2 = S_{yp}^2 \left(\frac{1-r^2}{n_p} + \frac{r^2}{n_a}\right)$

and $S_{yp}$ = standard deviation of the plot volumes on the permanent sample plots in the second inventory

$S_{\bar{y}t}^2$ = standard error of the mean volume in the second inventory, based on new sample plots

(see Nyyssönen 1972, p. 303).

The reliability of the estimate of mean volume in the inventory based on permanent sample plots is illustrated in Fig. 2.

The reliability of the growing stock estimate is the higher, the greater the correlation between the sample plots common to both inventories. There is also an optimal permanent sample plot proportion for each level of correlation.

If the correlation coefficient is 0.8, which according to Nyyssönen (1981) corresponds to a 5-year interval, then about 2 000 (30 %) permanent sample plots would suffice to reduce the standard error of the growing stock estimate by about 10 %, or to reduce the need for temporary sample plots in the second inventory by 10–20 % (see also Loetsch & Haller 1964, p. 259–277).



# 4. Simulation studies

## 41. Errors in tree diameter and height measurements

Breast height diameter is subject to a measurement error of 4–7 mm in terms of standard deviation (Nousiainen 1986, Päivinen 1987). The breast height diameter increment in one year in the Nurmes data is presented as a function of initial diameter in Fig. 3. Diameter increment was measured in one direction only, and was on the average 2 mm/year. The standard deviation was 6 mm. When measured twice at right angles, the standard deviation was reduced to 4 mm. It is obvious that only a small part of the variation in Fig. 3 was attributable to real variation in the increment.

According to Nousiainen (1986) and Päivinen (1987), tree height measurement is subject to a random measurement error with a standard deviation of 7 dm. The height increment in one year in Northeast Finland is presented as a function of initial diameter in Fig. 4 (Mattila 1983).

The effect of random errors in the diameter and height measurements on the stem and sample plot volumes was calculated using Taylor's series, a normally distributed random factor (mean value = 0, standard deviation = 0.5 cm) being added to the diameter of the pines in the different size classes. The height measurement error was simulated using a normally distributed random factor (mean value = 0, dispersion = 3 % of tree height).

The bias due to the persons carrying out the measurements was calculated in a corresponding manner by assuming the standard deviation in diameter measurement to be 1 mm, and that of height 0.2 m.

Table 1 shows, by way of a few examples, the effect of measurement errors on the stem volume of single trees.

The standard deviation of the difference between the two rounds of sample tree measurements in the Northern Karelia data was 0.016 m³ (13 %) for trees 13–19 cm in diameter, and 0.04 m³ (6 %) for trees 26–32 cm in diameter.

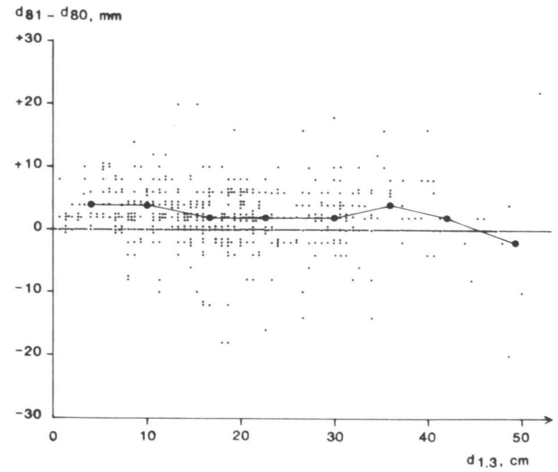


Fig. 3. One-year diameter increment on permanent sample plots in North Karelia.

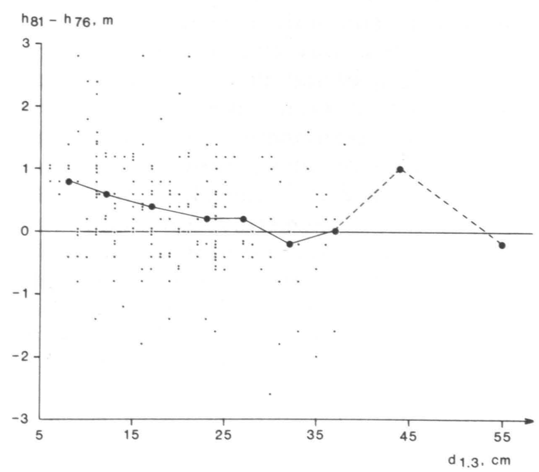


Fig 4. The five-year height increment as a function of the diameter for 192 trees measured on permanent sample plots in NE-Finland.

Table 1. Effect of the measurement errors on the stem volume of single trees.

| Diameter cm | Height m | Standard deviation of stem volume between Measurements % | Measurers % |
|---|---|---|---|
| 10 | 8.5 | 10.2 | 2.7 |
| 15 | 12.8 | 7.1 | 1.9 |
| 20 | 17.0 | 5.6 | 1.4 |
| 25 | 21.3 | 4.8 | 1.2 |
| 30 | 25.5 | 4.3 | 1.0 |

## 42. Simulation of the inventory based on permanent sample plots

The aim of the simulation study was to clarify the composition of the sampling error of the change in the growing stock volume. The sampling error of the change in volume is divided into its components; sampling errors attributable to increment, drain and mortality. Of particular interest is the effect of measurement errors on the increment estimate. The data for the simulation study consisted of 6871 simulated plots (see chapter 2).

All of the 6871 sample plots were assumed to have been measured in the first inventory, and varying proportions of them remeasured at the end of the 5-year period. The measurements made on the sample plots at the end of the period were simulated in such a way that 1 (for increment only), 2.5, 5, 10 and 20 % of the plots were picked out at even intervals to form a sample of "permanent" plots. Sampling was repeated 20 times (10 and 5 times in the cases of 10 and 20 % sampling intensities, respectively). Increment, drain and mortality for the 5-year period were calculated for the whole area on the basis of this sample. This gave 20, 10 and 5 different results. The standard deviations of the differences between these results and the result obtained for the total material were taken to be the empirically determined standard error of the sampling design (see Nyyssönen et al. 1967).

Drain and mortality on the sample plots were generalized as such, using the sampling intensity as the basis. Four different methods were used in the increment calculations:

1. The volume increment was derived as the average of the increment on the permanent sample plots.
2. As above, but the measurement error for tree diameters and heights was taken into account when simulating the precision of the increment calculations. A thus normally distributed random variable, p, with standard deviation

$$S_p = \frac{0.05\ V}{\sqrt{n}} \qquad (4)$$

(V = sample plot volume, $m^3$/ha and n = number of trees on sample plot) was added to the initial and final growing stock on each sample plot. On the basis of the arguments presented in chapter 4.1, it was assumed that standard deviation caused by the measurement errors is 5 % of the tree volume. In addition to random measurement errors, the bias caused by the people carrying out the measurements has to be taken into account. It was assumed in the calculations that the standard deviation of the bias would be 1 % of the sample plot's growing stock. Its effect decreases as the number of measurers increases. For example, if there are 8 crews, the bias is less than 0.35 % of the growing stock volume in two cases out of three.

3. The increment for the sample plots was derived employing increment functions developed by Nyyssönen & Mielikäinen (1978). In the functions, the increment of the growing stock is determined by the dominant tree species, site type, age of the stand, and the growing stock volume. The measurements made on sample plots were used in adjusting the level of the increment functions, separately in each sampling. Increment functions were then used for all initial sample plots.

4. As above, but the measurements that include measurement errors were used for adjusting the increment models.

Fig. 5 shows the results of the sampling simulation, the increment having been calculated using method 1. Only permanent sample plots are used. Considerably more





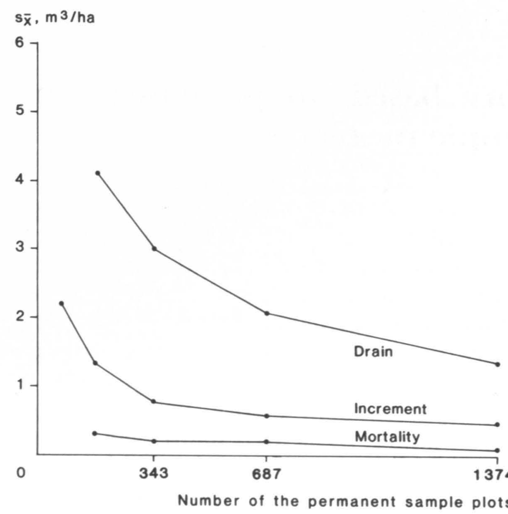


Fig. 5. The dependency of standard errors as a function of the number of permanent plots in a sampling simulation.

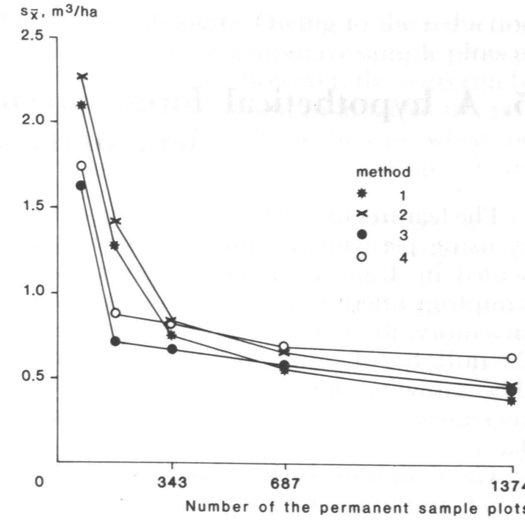


Fig. 6. The reliability of the increment estimate calculated from permanent sample plots using various methods.

sample plots are required in order to obtain a reliable estimate of the drain using permanent sample plots than those needed for increment estimation. Lengthening of the measurement interval may, however, alter the situation in the sense that as the drain becomes more evenly distributed over the sample plots, the ratio of reguired drain/increment sample plots decreases.

It can be concluded that the error in the change is mainly attributable to the sampling error of the drain estimate. Permanent sample plots are an efficient means of eliminating measurement errors in drain and mortality. However, when the variation in the drain is high, the sampling error also remains high.

The standard errors of the increment estimates when methods 2, 3 and 4 are used are given in Fig. 6. Method 1 (see Fig. 5) is given as a reference.

The random variation in the diameter measurements is no more significant when a very large number of trees are measured. The variation caused by the measurement errors is predominantly dependent on the variation between the measurers and, therefore, on the number of measurers. If, for example, there are only two people carrying out the initial and final measuring, then (with 10 % sampling intensity) the measurement errors easily constitute approximately as large a source of random error in the increment estimate as does the sampling error. Fig. 6, however, refers to a situation where there are 8 measurers on both occasions.

Method 4 is closest to a real-life situation. It takes into account the measurement errors made on permanent sample plots. The adjustment method improves the result in cases where the sample is small and the sampling error is at its maximum. The differences decrease as the sample grows in size. The great variation caused by the regression method when the highest sampling intensities are used is partly explained by the small number (= 5) of observations.

## 5. A hypothetical forest inventory based on permanent and temporary sample plots

The features of a fictitious forest inventory using permanent sample plots are presented in Table 2. Assuming the present sampling intensity used in national forest inventory, the land area in the example is 2.8 mill. ha, of which 75 % is forested area. The growing stock volume is 93 $m^3$/ha, increment 4.2 $m^3$/ha/a and drain 2.9 $m^3$/ha/a.

The design of the first inventory corresponds to the inventory design used in the 7th National Forest Inventory in Finland. Time consumption per tract is obtained from actual time studies (Päivinen and Yli-Kojola 1983), and the standard errors of the mean volume and increment are derived using formulae for random sampling. No permanent sample plots are established.

In the second inventory, the permanent sample plots are established on permanent tracts (8 plots on each). Both temporary and permanent tracts are still one day's work for an inventory crew. Using this design, the cost ratio between permanent and temporary plots is 1.6. According to Ware and Cunia (1962), this cost ratio and a correlation coefficient of 0.8 yield an optimum fraction of permanent plots of 0.18 when only the mean volume of the growing stock is estimated.

In the third inventory, no new permanent sample plots are established but it is assumed that the plots of the 2nd inventory are remeasured in the following inventories.

The standard errors of the mean volume and its change are derived using formulae (3) and (2) respectively, except in the case of the standard error of the change between the 1st and 2nd inventory, where simple error propagation through variances is used. The standard errors of the increment are estimated by assuming the standard deviation of the plot increments to be 17.3 $m^3$/ha/5a. In the 3rd inventory the measurement errors disturb the increment values for the permanent sample plots, and therefore the precision is lower even though the number of increment sample plots is higher than before. Drain and mortality cannot be reliably determined on the basis of a single inventory. When interpreting the estimates for standard errors in Table 2, it must be kept in mind that effects of the systematic sample and clustering are not taken into the consideration.

Table 2. Characteristics of the successive forest inventories based on permanent sample plots.

| | 1st | | 2nd inventory | | 3rd |
|---|---|---|---|---|---|
| Tracts | 436 | | 510 | | 510 |
| On forest and scrub land: | | | | | |
| Temporary growing stock sample plots | 5 566 | | 3 848 | | 3 782 |
| Temporary increment sample plots | 1 305 | | 1 305 | | - |
| New permanent sample plots | - | | 1 718 (25 %) | | - |
| Remeasurement | - | | - | | 1 718 (31 %) |
| Total nr. of sample plots | 6 871 | | 6 871 | | 5 500 |
| Time consumption/tract | 8.8 h | | 8.7 h | | 7.5 h |
| Relative cost | 100 | | 115 | | 100 |
| Standard errors, $m^3$/ha | | | | | |
| Mean volume | 1.09 | | 1.09 | | 1.09 |
| Change in mean volume between inventories | | 1.54 | | 1.15 | |
| Increment/5a | 0.48 | | 0.48 | | 0.50 (2.4 %) |
| Drain/5 a | ? | | ? | | 1.2 (8 %) |
| Mortality/5 a | ? | | ? | | 0.1 (13 %) |



The aim of a national forest inventory based on permanent sample plots is to preserve the present-day level of reliability of the estimates for volume, increment and drain. The costs of the 2nd inventory are higher than those of the first owing to the need for both measuring increment sample plots as today and for establishing permanent sample plots. Owing to the reduction in the number of temporary sample plots in the 3rd inventory, however, the costs can be expected to fall to approximately the previous level, but only in the case where no new permanent sample plots are established.

Some extra costs also arise due to the extra arrangements needed to carry out the remeasurements that have to be done in a certain year. Organization of the field work would be more complex than in inventories based on temporary sample plots. However, the benefits are better estimates of drain and mortality. The development of individual trees, and as well as other components of forest ecosystem, can also be monitored.

## 6. Conclusions

The reliability of estimates concerning the volume of the growing stock can be slightly improved (or the number of temporary sample plots required can be reduced) by using permanent sample plots. Over a long period (more than 10 years) permanent sample plots do, however, lose a lot of their significance in this respect.

The use of permanent sample plots in inventorying the change in the growing stock volume is more efficient than doing it via separate, repeated inventories. As the period between the measurement lengthens, the usefulness of permanent plots diminishes.

It is concluded that, owing to errors in the diameter measurements, increment estimation requires more permanent sample plots than temporary plots, where the increment is measured by boring. If the sample is small and the sampling errors thus large, then the measurement error in permanent plots does not play any significant role in the total error. If the period involved in increment determination is long, the significance of the measurement errors is reduced, too.

According to the simulation studies, the combined use of increment functions and increment measurement seems to be a promising approach. In this case precise measurements are needed.

When estimating the drain, errors in enumerating the removed trees can mostly be avoided through the use of permanent sample plots. Owing to the spatial variation in the drain, the sampling error of the drain is still the most significant single factor preventing accurate estimation of the change in the growing stock. This also applies to mortality. The measurement error in determining the time of tree death on permanent sample plots is smaller than that on temporary plots but, due to the low natural mortality in managed forests, the sampling error is still large.

As the sampling error of the drain estimate is the most important factor when the change in the growing stock is derived, the number of drain sample plots should be greater than that of the increment plots.

It may be appropriate to establish permanent sample plots of varying levels:

1. Sample plots whose centre point and/or the route to the plot are/is marked. When remeasured, changes in the soil and stand characteristics are recorded in such a way that, for example, it is possible to estimate the extent of intermediate and final cuttings

on these sample plots. Remote sensed data can probably be employed in such measurements, too.

2. Sample plots on which (in addition to the above) all the trees died or felled are tallied in order to determine the stem diameter distribution of the drain.

3. Permanent sample plots for increment measurement. All trees are tallied and the tree dimensions measured with particular care.

The principle of secrecy and the possibility of bias caused by different treatment applies, above all, to sample plots in groups 1 and 2. The sample plot network can be prevented from becoming common knowledge by both inconspicuous marking of sample plots in the field and randomization of tract locations.

If the marking technique can be made flexible, perhaps all NFI sample plots could be put into group 1.

If determining the increment of the trees and monitoring the forest ecosystem are set as the ultimate objectives, instead of changes in variables associated with growing stock volume, then the inventory design would be different to that discussed here. In such a case special attention has to be paid to the comprehensive and careful measurement of the plots. Only a relatively small number of this kind of sample plots could be afforded.

In cases where the objectives of the national forest inventory are manyfold, simplicity as the guidelines for the inventory design may have to give way to complexity in layout, if the reguirement of optimal design are to be met.

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