Calculation and Comparison of Different Permanent Sample Plot Types

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A calculation procedure is presented for calculating and analysing remeasured permanent sample plots. Data for eight different fixed and variable size plot types were simulated on the basis of two stands whose trees were mapped and measured in 1982 and 1986. The accuracy and efficiency of the plot types were assessed and compared.

The calculation procedure is based on treewise expansion factors and the division of trees sampled into state/measurement classes. Nine classes were required for variable size plots and six for fixed size plots. A relascope plot with basal-area factor 1 (m^2/ha) proved to be most efficient for estimating basal-area at a given time and a fixed size circular plot with radius 10 m for estimating basal-area increment over a given time period.

The main problems were related to the estimation of non-measurable variables, e.g., the initial diameters of ingrowth trees, i.e., trees having passed the threshold size during the measurement period. Most problematic were cut trees belonging to the ingrowth or sample enlargement classes. It is nevertheless thought that the system is appropriate for monitoring forest changes and making sensitivity analyses with permanent sample plots.

Keywords forest inventories, forest monitoring, optimum sampling unit, permanent plot analysis.
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1 Introduction

If growth and other changes are of special importance then permanent sample plots should be considered. This has been demonstrated by several authors, e.g., Beers (1962), Ware and Cunia (1962), Loetsch et al. (1964), Nyyssönen (1967), Martin (1982), van Deusen et al. (1986), Roesch et al. (1989, 1991), Päivinen and Yli-Kojola (1989), and Schmid-Haas (1992).

Lihtonen (1959) claims that the first experiment with permanent inventory plots was established in Finland by Lindholm in the 1920s in the forests around Rauma. Since the 1950s permanent sample plots have been established and applied in several inventories (Nyyssönen 1981). However, the use of this data has been limited and variable and many companies have hesitated to continue the measurements after a few repetitions.

Permanent sample plots have been used commonly in the USA since the 1960s and since the 1980s in many other countries especially for national inventories. According to Adlard (1993) "a large forest company in Alberta set up a continuous forest inventory in the late fifties which led to a system of permanent sample plots. There are now 3000 plots measured every 10 years supplying data for growth models and management plans. Also in the fifties a network of sample plots were installed in the coniferous plantations of East and Central Africa (Kenya, Uganda, Tanzania and Malawi). Many remeasurements following carefully defined procedures have resulted in a growing database now fueling simulation models that were inconceivable at the time the programme was started. Permanent monitoring plots were set up in the mixed tropical forests in many countries during the same period."

Permanent plots were introduced to the Finnish national forest inventory in 1974 when two-phase sampling was used in the northern part of Finland. In southern Finland a systematic sample of permanent plots was established in 1985. In other Nordic countries and some Central European countries permanent sample plots have been used since the 1980s.

A general computerized system for managing, calculating, and analysing permanent plot data is currently lacking in Finland. In order to create such a system, it is first necessary to *derive and study appropriate methodology for calculating permanent sample plot information.* The second objective is to *study the properties of various permanent sample plot types.*

Plot types will be studied by simulating plot measurements for eight different plot types in two forest stands whose trees were mapped and measured on two occasions. Simple circular plots with 15 m radii are used as reference units. Consequently, the study is aimed at finding an appropriate way to measure stand characteristics, including change variables, for a circular area of approximately 700 square metres. This type of layout has become more important with the increasing requirement for georeferenced information.

2 Material and Method

2.1 General Outline

Properties of different plot types and calculation methods were compared by simulating plot measurements in two experimental areas with all trees located and measured on two occasions, *Time 1* and *Time 2*. Before the actual simulation, missing *Time 2* values for cut trees and *Time 1* values of ingrowth trees were estimated and added to the tree database. These values and all measured values were then considered as "true" tree values. Next, a dense, systematic set of plot centres was generated and plot measurements were simulated for each plot type. The plot values at *Time 1* and *Time 2* and change values were calculated for each plot and plot type using alternative methods. These results were finally studied and compared to those calculated with the reference plot type. Tree class distributions, accuracy, and efficiency of different plot types were studied.

Comparisons were made on the basis of basal area. The main measures used for assessing the performance of alternative sample units were the root mean square errors of basal area and basal-area increment. It is assumed that the conclusions to be drawn can be extended to such variables as volume also.

2.2 Material

The empirical material used was derived from two forest areas owned by Helsinki University and located in the southern coastal region of Finland. Both areas, *Area 1* and *Area 2,* are somewhat larger than one hectare. *Area 1* is homogeneous in respect to site, tree species composition, and age whereas *Area 2* is quite heterogeneous. Each tree with a breast-height diameter larger than 5 cm was mapped and measured on two occasions, in 1982 and 1986.

In *Area 1*, the species, state (*living, dead,* or *cut*), and breast-height diameter of all standing trees were assessed on both occasions. Height and upper diameter (at 6 m height) of every fifth tree was measured. The total number of trees measured was 2127 in 1982 and 2166 in 1986. Of these only one tree had been cut during the measurement period.

In *Area 2*, the species, state, breast-height diameter, upper diameter, and height of all trees were assessed in 1982. The total number of trees measured was 1527. In 1986, the species and state of all trees either living, cut or dead and breast-height diameter for all standing trees were assessed. Upper diameter and height of only some trees were assessed. The total number of trees tallied was 1754. Of these, 262 had been cut during the measurement period.

The numbers of selected plot centres were 126 in *Area 1* and 141 in *Area 2*. The minimum allowable distance from a plot centre point to the forest boundary was set to 18 m. Plot measurements were simulated for the following eight plot types:

C15 Simple circular plot of 15 m radius,
C10 Simple circular plot of 10 m radius,
C5 Simple circular plot of 5 m radius,
C15_6 Concentric circular plot of 15 m radius for trees with ***dbh*** at least 20 cm and 6 m for trees with ***dbh*** less than 20 cm,
C10_5 Concentric circular plot of 10 radius m for trees with ***dbh*** at least 20 cm and 5 m for trees less than 20 cm,
R1_15 Relascope plot with BAF 1 m^2/ha and maximum radius 15 m,
R2_15 Relascope plot with BAF 2 m^2/ha and maximum radius 15 m, and
R4_15 Relascope plot with BAF 4 m^2/ha and maximum radius 15 m.

Plot types *C15*, *C10*, and *C5* are fixed-size plots and the others variable-size plots. Plot type *C15* was used as the reference plot type, i.e., results calculated for it were considered as "true" values and used as reference values in the plot comparisons.

In *Area 1* the breast-height diameter distributions resembled a 'two-peaked' distribution on both occasions. In *Area 2* they resemble an 'inverse J' distribution. The distribution of cut trees was quite similar to that of living trees. This indicates the use of selective thinning.

On plot types *C15_6* and *C10_5* trees larger than or equal to 20 cm were sampled with a larger fraction than trees smaller than 20 cm. In *Area 1* a relatively large number of trees have a ***dbh*** close to 20 cm. The proportion of trees larger than 20 cm changed during the measurement period from 30.4 (1982) to 37.4 % (1986) in *Area 1* and from 17.2 to 17.8 % in *Area 2*.

2.3 Tree Classification

The trees on a plot are assumed to have been measured on at least two occasions: *Time 1* and *Time 2*. If the plot size is fixed the trees measured can be classified into six classes consisting of tree status (living, cut, dead), and measurement status (remeasured, ingrowth). The ingrowth class includes trees that have been measured only at *Time 2* and have grown over the threshold size during the measurement period.

If variable-size plots are used, e.g., relascope plots or concentric circular plots, the measurement status is increased by a class of plot enlargement trees, trees which have grown large enough to be included in the plot at *Time 2* and were too small to be included at *Time 1.* These trees have been called 'nongrowth trees' by Martin (1982) and van Deusen et al. (1986). The total number of tree classes for variable-size plots is then nine (combinations of three tree status and three measurement status). The following symbols are used to specify the tree classes:

LR Living trees, remeasured
LI Living trees, ingrowth trees
LE Living trees, plot enlargement trees
CR Cut trees, remeasured
CI Cut trees, ingrowth trees
CE Cut trees, plot enlargement trees
MR Dead or mortality trees, remeasured
MI Dead trees, ingrowth trees
ME Dead trees, plot enlargement trees

2.4 Calculation of Plot Component Variables

A plot component consists of all those trees belonging to one of the nine alternative tree classes. The plot components are further specified according to time referred to in estimation and measurement occasion as *Sample 1* or *Sample 2*. For example, LR(1,2) refers to living trees which have been measured at *Time 1* and *2* and the plot component variable is estimated for *Time 1* on the basis of *Sample 2*. *Sample 2* is, in case of variable-size plots, usually larger than *Sample 1* and therefore it may be sensible to use it for estimating *Time 1* variables.

Plot component variables are primarily state variables. For example, the volume of remeasured cut trees, CR, at *Time 1* is a state variable. Change variables are estimated as the difference in state variables of *Time 2* and *1*. For example, the volume increment of plot component CR can be estimated as the difference of volumes of CR(2,1) and CR(1,1).

The expansion factor transforms tree variables to per hectare variables and is calculated by A/aj, where A refers to the unit area, a hectare in this case, and a_j to the plot area for tree j. A plot component variable is the sum of per hectare variables of the trees belonging to the given tree class. Depending on which sample is used, the estimates for a plot component are usually different.

No simple answer can be given to the question which sample, *Sample 1* or *Sample 2* should be used for estimating plot component variables. The advantage of *Sample 2* is that, on variable-size plots, it is larger and thus represents the site better than *Sample 1*. On the other hand, those trees which have been cut during the measurement period can be measured only for stump variables with *Sample 2*. Since it is expected that both samples lead to unbiased estimates, both samples could be combined by suitable weights. The optimum sample or combination of samples for estimating plot component variables depends on the plot component in question. Table 1 illustrates the problem and serves as a guide for selecting appropriate samples.

Two guiding principles can be used for selecting the appropriate sample to calculate plot component variables; estimation should be based on real measurements and a large sample. Accordingly, those alternatives marked by ++ in the S2 columns are the best choices.

Table 1 shows that the plot components can be based on direct measurements in the case of remeasured trees, either living or dead. For all other components direct measurements must be

Table 1. Applicability of *Sample 1* and *Sample 2* for estimating plot component variables*.

Tree status and time	Measurement status and sample					
	Remeasured		Ingrowth		Enlargement	
	S1	S2	S1	S2	S1	S2
Living, *Time 1*	++	++	• •	+-	• •	+-
Living, *Time 2*	++	++	• •	++	• •	++
Living, Change	++	++	• •	+-	• •	+-
Cut, *Time 1*	++	-+	• •	--	• •	--
Cut, *Time 2*	+-	--	• •	--	• •	--
Cut, Change	+-	--	• •	--	• •	--
Dead, *Time 1*	++	++	• •	+-	• •	+-
Dead, *Time 2*	++	++	• •	++	• •	++
Dead, Change	++	++	• •	+-	• •	+-

* The symbol + means that the variable can be measured, the symbol - that it must be estimated with models, and the symbol • that *Sample 1* is not a feasible alternative. The first symbol refers to the expansion factor, and the second to the tree variable.

Table 2. Equations for calculating plot variables.

Number	State of living trees
1	LR(1,1) + CR(1,1) + MR(1,1)
2	LR(1,2) + CR(1,1) + MR(1,1) + LE(1,2)
3	LR(1,2) + CR(1,1) + MR(1,2) + LE(1,2) + ME(1,2)
4	LR(2,1) + LI(2,2)
5	LR(2,2) + LE(2,2) + LI(2,2)
	State of cut trees
6	CR(1,1)
7	CR(2,1) + CI(2,2)
	State of dead trees
8	MR(1,1)
9	MR(2,1) + MI(2,2)
10	MR(2,2) + ME(2,2) + MI(2,2)
	Increment of remeasured trees
11	LR(2,1) – LR(1,1)
	Increment of living trees
12*	LR(2,1) – LR(1,1) + LI(2,2)
13	LR(2,1) – LR(1,1) + LI(2,2) – LI(1,2)
14*	LR(2,2) – LR(1,2) + LE(2,2) – LE(1,2) + LI(2,2)
15	LR(2,2) – LR(1,2) + LE(2,2) – LE(1,2) + LI(2,2) – LI(1,2)
	Increment of cut trees
16*	CR(2,1) – CR(1,1) + CI(2,2)
	Increment of dead trees
17	MR(2,1) – MR(1,1) + MI(2,2)
18*	MR(2,2) – MR(1,2) + ME(2,2) – ME(1,2) + MI(2,2)
	Increment of total drain
19*	CR(2,1) – CR(1,1) + CI(2,2) + MR(2,1) – MR(1,1) + MI(2,2)
	Total increment
20*	LR(2,2) – LR(1,2) + LI(2,2) + CR(2,1) – CR(1,1) + CI(2,2) + MR(2,1) – MR(1,1) + MI(2,2)
21*	LR(2,2) – LR(1,2) + LE(2,2) – LE(1,2) + LI(2,2) + CR(2,1) – CR(1,1) + CI(2,2) + MR(2,2) – MR(1,2) + ME(2,2) – ME(1,2) + MI(2,2)

* The ingrowth element of the estimator has been calculated as total ingrowth instead of differential ingrowth.

substituted by increment models. These models can be calibrated with the direct increment measurements. Cut ingrowth and enlargement trees create a specific problem because there are no direct measurements available. These components cannot, however, be neglected without bias in estimating total cut and increment.

Plot variables, e.g., volume increment, m^3/ha, can be calculated by adding their respective plot components. A list of equations considered is shown in Table 2.

Total ingrowth refers to the *Sample 2* total, e.g., the basal area of ingrown trees at *Time 2* whereas differential ingrowth refers to the difference in *Sample 2* ingrowth at times 2 and 1.

3 Results

3.1 Accuracy

The unbiasedness and accuracy of a plot type was studied on the basis of plotwise differences, where difference (i) for plot i was calculated as $\mathbf{X}(i) - \mathbf{X}(i,ref)$, and where $\mathbf{X}(i,ref)$ refers to the corresponding plot reference value. The expected value for $\Delta(i)$ or bias equals 0. Accuracy was assessed by the mean square of $\Delta(i)$ (**MSE**) and estimated as $\Sigma(\Delta(i))^2 / n$. The results are presented in Tables 3 and 4.

Sample 2 estimates are more accurate than *Sample 1* estimates for variable-size plots. The difference in the error variances is roughly 10 % for concentric circular plots and 20 % for relascope plots. This is true both for the estimation of basal area and basal-area increment. The corresponding differences for fixed-size plots, caused by ingrowth trees, are minimal.

Minor bias was observed, i.e., $\Sigma\Delta(i)$ differed from zero. Bias was not, however, regarded as worth studying in more detail in this case since individual estimates were more important than population estimates.

Table 3. Plot type comparison in estimating Basal area at *Time 1*, **BA**(*1*), or *Time 2*, **BA**(*2*).

Equation and plot component		Area	*C15* Reference m^2/ha	*C10*	*C5*	*C15_6*	*C10_5*	*R1_15*	*R2_15*	*R4_15*
				100 · RMSE/reference value						
				Standing trees						
1	**BA**(*1*)	1	22.625	13.2	30.8	16.8	21.2	**13.0**	20.5	31.3
1	**BA**(*1*)	2	18.585	23.2	55.0	18.0	30.1	**17.7**	27.3	42.1
3	**BA**(*1*)	2	18.585	23.2	55.0	16.9	28.9	**15.7**	26.5	38.9
2	**BA**(*1*)	2	18.585	23.2	55.0	16.9	28.9	**15.7**	26.5	38.9
4	**BA**(*2*)	1	26.722	12.8	30.3	16.9	20.9	**13.0**	20.0	31.1
5	**BA**(*2*)	1	26.722	12.8	30.3	15.2	20.2	**11.3**	18.1	28.0
4	**BA**(*2*)	2	16.265	25.7	58.6	**22.5**	35.7	23.0	33.3	49.2
5	**BA**(*2*)	2	16.265	25.7	58.6	20.8	33.8	**19.8**	31.9	43.6
				Cut trees						
6	**BA**(*1*)	2	4.552	59.7	119.2	**30.0**	61.4	35.8	56.0	85.6
7	**BA**(*2*)	2	4.937	58.6	116.9	**31.7**	60.9	38.0	58.1	86.6
				Dead trees						
8	**BA**(*1*)	1	0.059	**208.5**	655.9	506.8	655.9	396.6	645.8	628.8
8	**BA**(*1*)	2	0.098	**211.2**	379.6	248.0	388.8	257.1	473.5	727.6
9	**BA**(*2*)	1	0.067	**207.5**	623.9	504.5	623.9	401.5	659.7	619.4
10	**BA**(*2*)	1	0.067	**207.5**	623.9	504.5	623.9	353.7	611.9	562.7
9	**BA**(*2*)	2	0.100	**208.0**	379.0	251.0	387.0	265.0	485.0	722.0
10	**BA**(*2*)	2	0.100	**208.0**	379.0	251.0	387.0	251.0	462.0	713.0

3.2 Efficiency

The efficiency of a plot type was studied in relation to the plot variables presented in Tables 4 and 5. The general formula applied for calculating efficiency, **EFF**(*i*), for plot type *i* is:

$$\mathbf{EFF}(i) = \mathbf{CONSTANT} / (\mathbf{MSE}(i) \cdot \mathbf{COST}(i)) \quad (22)$$

where **COST**(*i*) refers to the average measuring cost of plot type *i*. The constant is determined in a way which yields the value 100 for the most efficient plot type. Thus the efficiency values of the other plot types are less than 100 and show efficiencies in relation to the most efficient plot type.

Table 4. Plot type comparison in estimating Basal-area increment from *Time 1* to *Time 2*, **ΔBA**.

Equation and plot component		Area	*C15* Reference m^2/ha	*C10*	*C5*	*C15_6*	*C10_5*	*R1_15*	*R2_15*	*R4_15*
				100 · RMSE/reference value						
11	**ΔBA**	1	4.141	**12.4**	31.2	18.6	23.1	16.0	20.6	32.2
11	**ΔBA**	2	2.190	**24.5**	53.7	34.8	44.9	38.2	55.1	79.6
12	**ΔBA**	1	4.156	**12.2**	31.0	18.6	22.8	15.5	20.4	33.2
14	**ΔBA**	1	4.156	**12.2**	31.0	17.2	22.3	12.9	19.4	29.2
12	**ΔBA**	2	2.330	**23.4**	51.1	34.1	43.6	41.4	60.8	76.9
14	**ΔBA**	2	2.330	**23.4**	51.1	31.7	40.7	36.0	54.9	65.3
13	**ΔBA**	1	4.145	**12.4**	31.1	18.6	23.0	15.8	20.5	32.3
15	**ΔBA**	1	4.145	**12.4**	31.1	17.0	22.5	13.0	19.6	28.5
13	**ΔBA**	2	2.214	**24.3**	53.1	34.6	44.5	38.3	55.6	78.6
15	**ΔBA**	2	2.214	**24.3**	53.1	32.0	41.3	32.0	48.6	66.3
16	**ΔBA**	2	0.385	**48.6**	99.0	52.5	64.2	66.0	89.6	109.9
17	**ΔBA**	1	0.008	**254.1**	585.4	632.6	585.4	537.3	940.5	574.5
18	**ΔBA**	1	0.008	**254.1**	585.4	632.6	585.4	431.3	827.0	527.9
17	**ΔBA**	2	0.002	**300.0**	1050.0	950.0	1050.0	1250.0	1950.0	950.0
18	**ΔBA**	2	0.002	**300.0**	1050.0	950.0	1050.0	1050.0	1650.0	900.0
20	**ΔBA**	1	4.164	**12.2**	30.9	18.6	22.8	15.6	20.2	33.0
21	**ΔBA**	1	4.164	**12.2**	30.9	16.9	22.2	12.9	19.3	29.1
20	**ΔBA**	2	2.717	**19.3**	45.3	30.7	38.2	36.0	53.8	66.7
21	**ΔBA**	2	2.717	**19.3**	45.3	28.6	35.5	31.7	49.0	57.6

Table 5. Relative accuracies (upper row) and efficiencies (lower row) of alternative plot types for some estimators according to assumptions of 15 min plot establishment and 300 m distance between successive plots.

Eq.	Plot characteristic	MIN(RMSE(*i*)) m²/ha	Plot type *C10*	*C5*	*C15_6*	*C10_5*	*R1_15*	*R2_15*	*R4_15*
			Area 1						
1	Basal area at the beginning	?	96.6	17.8	59.8	37.6	**100.0**	40.0	17.2
	of the period		89.1	31.7	52.7	49.8	**100.0**	56.8	31.3
4	Basal area at the end	3.431	**1.00**	17.9	58.0	37.6	97.5	41.0	17.0
	of the period		94.5	32.8	52.46	51.0	**100.0**	59.5	31.9
5	Basal area at the end	3.032	78.1	14.0	55.5	31.6	**100.0**	39.1	16.4
	of the period		72.0	25.0	48.9	41.8	**100.0**	55.3	30.0
12*	Basal-area increment	0.509	**100.0**	15.6	43.1	28.9	62.3	35.9	13.6
	during the period		**100.0**	30.2	41.3	41.5	67.6	55.2	26.9
14*	Basal-area increment	0.509	**100.0**	15.6	50.7	30.1	90.5	39.9	17.6
	during the period		**100.0**	30.2	48.8	43.2	**98.2**	61.2	34.9
20*	Basal-area increment	0.508	**100.0**	15.6	43.1	28.6	61.3	36.5	13.7
	during the period		**100.0**	30.2	41.2	41.1	66.5	56.0	27.1
21*	Basal-area increment	0.508	**100.0**	15.6	52.2	30.2	89.5	39.9	17.6
	during the period		**100.0**	30.2	50.0	43.3	97.1	61.3	34.8
			Area 2						
1	Basal area at the beginning	3.288	45.7	8.1	86.4	29.6	**100.0**	35.1	16.3
	of the period		34.4	10.2	76.9	32.9	**100.0**	40.9	22.2
3	Basal area at the beginning	2.918	45.7	8.1	86.4	29.6	**100.0**	35.1	16.3
	of the period		34.4	10.23	76.9	32.9	**100.0**	40.9	22.2
4	Basal area at the end	3.666	77.0	14.8	**100.0**	40.0	95.7	45.8	21.0
	of the period		60.6	19.4	93.1	46.5	**100.0**	55.8	29.9
5	Basal area at the end	3.213	59.1	11.4	89.9	34.2	**100.0**	38.3	20.5
	of the period		44.5	14.3	80.1	38.1	**100.0**	44.6	27.9
12*	Basal-area increment	0.546	**100.0**	21.0	47.2	28.9	32.1	14.9	9.3
	during the period		**100.0**	35.1	55.8	42.7	42.6	23.0	16.8
14*	Basal-area increment	0.546	**100.0**	21.0	54.7	33.1	42.4	18.2	12.9
	during the period		**100.0**	35.1	64.7	48.9	56.2	28.2	23.3
20*	Basal-area increment	0.525	**100.0**	18.2	39.6	25.6	28.8	12.9	8.4
	during the period		**100.0**	30.4	46.8	37.9	38.7	20.0	15.6
21*	Basal-area increment	0.525	**100.0**	18.2	45.8	29.7	37.2	15.5	11.3
	during the period		**100.0**	30.4	54.11	43.8	49.4	24.1	20.4

* The ingrowth element has been calculated as total ingrowth instead of differential ingrowth.

The study by Nyyssönen et al. (1971) was applied to making assumptions on time expenditure. The total measurement cost for each plot type was estimated by first assuming that daily working time equals 8 hours or 480 minutes, traveling time, T_{road}, to the first plot and back from the last plot takes 60 min, pauses, T_{paus}, make up 80 min, and efficient measurement time, T_{mes} is 340 min. The ratio between daily non-measurement and measurement time, *f*, was then calculated as:

$$f = (T_{road} + T_{paus}) / T_{mes} \approx 0.4 \qquad (23)$$

The measurement of one plot was assumed to require the following time:

- Plot establishment, T_{est}, 5 min, 15 min, or 45 min (higher figures refer to first time establishment, and the lower ones to remeasurements)
- Field travel time, T_{walk}, 4.0 + 0.04 · *dst* min/plot, where *dst* was either 100 m, 300 m or 900 m, and
- Tree tally and height measurement, T_{tally}, 1.5 + 1.6 · *n* min/plot, *n* is the number of trees tallied per plot.

The total measurement cost C, or total measurement time, min, was finally estimated as:

$$C = (1 + f) \cdot (m \cdot (T_{est} + T_{tally}) + (m - 1) \cdot T_{walk}) \qquad (24)$$

where
m = number of plots measured and
T_{tally} = average tree tally time/plot.

4 Discussion

It was assumed that on permanent sample plots each tree is measured and recorded individually. On the basis of two successive measurements the trees of a plot were divided into nine different tree classes based on three status classes, living, cut and dead trees, and three measurement classes, remeasured, ingrowth and plot enlargement trees. If fixed-size plots are used the plot enlargement class is void.

Not all trees can be measured for all variables needed for a complete analysis of the state of a plot. This is true especially for trees cut during the period. Values for the time at which the tree was cut must be based on *Time 1* measurements and growth models. For that purpose, the exact time of cut should also be known or estimated. Accurate estimates for cut ingrowth and plot enlargement trees are most difficult to obtain. One is also likely to miss some cut ingrowth and plot enlargement trees in the field which results in negative bias. It is thus suggested that variables for cut plot components be estimated according to *Sample 1*. This will, on the other hand, lead to the underestimation of cut ingrowth plot components. Fortunately, the importance of this component is often marginal. If not, the estimation of the component should be based on separate models.

In spite of a fairly large number of simulated sample plots, 126 for *Area 1* and 141 for *Area 2*, the average differences for basal area and basal-area increment did occasionally differ from zero significantly. The smallest variable-size plots, *C10_5* and *R4_15* overestimated basal area by 2.29 and 2.64 % and basal-area increment by 3.29 and 4.12 %. No other reasons for this "bias" were found than the limited number of sample units and the location of sample units in respect to forwarding tracks.

Plot component variables and plot variables can be estimated in more than one way. *Sample 2* yields more accurate estimates than *Sample 1* when the size of the plot is dependent on tree size (Tables 2 and 5). Even *Time 1* variables were estimated about 15 % more efficiently when *Sample 2* was used instead of *Sample 1*. The difference increased to some 20 % for *Time 2* and increment variables. The differences were larger for relascope plots than for concentric circular plots.

In considering the differences between plot types one should remember the somewhat exceptional outline of the study. The population to be estimated was not defined as all trees belonging to the study areas but the trees belonging to the reference sample plots.

The efficiency studies showed some interesting results. Table 6 illustrates relative efficiencies when *Sample 2* was used.

The largest variable-size plot, *R1_15*, turned out to be superior for estimating basal area and this superiority became more evident with heter-

Table 6. Efficiencies of alternative sample plots in varying inventory conditions.

Plot variable	Plot type *C10*	*C5*	*C15_6*	*C10_5*	*R1_15*	*R2_15*	*R4_15*
Basal area at *Time 2* (Eq. 5)							
15 min/300 m (from Table 5)	58	20	64	40	**100**	50	23
5 min/100 m	54	26	61	43	**100**	56	38
45 min/900 m	63	17	67	37	**100**	44	22
Basal-area increment (Eq. 21)							
15 min/300 m (from Table 5)	**100**	30	52	44	73	43	28
5 min/100 m	**100**	40	54	52	78	52	39
45 min/900 m	**100**	22	50	38	68	36	22

ogeneous forest conditions (*Area 2*). Assumptions concerning the efficiency calculations, time of plot establishment and walking distance from one plot to another, affect the relative efficiencies but do not change the order of the two best plot types (*R_15* and *C15_6*) and two worst plot types (*C5* and *R4_15*).

The largest fixed-size plot, *C10*, was superior for estimating basal-area increment. Again, the superiority was more significant with heterogeneous forest conditions (*Area 2*). Plot establishment time and walking distance do not affect the order of plot types. The best plot types are *C10* and *R1_15* and the worst *R4_15* and *C5*. The importance of small trees is greater when total ingrowth is applied instead of differential ingrowth.

The aim of the study was to outline suitable plot types and calculation methods for estimating forest stand characteristics for local conditions. The study does not give a direct answer to the question of which is the best unit for estimating mean variables for a large forest population. The background to taking localized information as a primary problem stems from the need to monitor changes in forests locally.

A fixed-size circular plot with an approximate radius of 10 m seems most desirable for monitoring changes. However, many details need to be studied further. In addition to basal area, other stand characteristics should also be scrutinized. More research is also required to determine the optimum sample unit for a specific situation. Clusters of plots should also be considered. Time series analysis and expert systems also offer interesting possibilities.

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