CHAPTER 11

THE FINNISH NATIONAL FOREST INVENTORY

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11.1 INTRODUCTION

The National Forest Inventory has been producing large-area forest resource information on Finland since the beginning of the 1920s. The ninth inventory rotation was conducted in 1996-2003 and the tenth began in 2004.

The information generated by the Finnish National Forest Inventories (NFI) has traditionally been made use of in large-area forest management planning, e.g. in the planning of cutting, silviculture and forest improvement regimes at the regional and national levels, in decisions concerning forest industry investments and as a basis for forest income taxation. It has also provided forest resource information for national and international statistics such as the United Nations/FAO Forest Resource Assessment procedure and the Ministerial Conference on the Protection of Forests in Europe (MCPFE). It currently also produces information on forest health status and damage, biodiversity and carbon pools and changes in these for the Land Use Land Use Change (LULUCF) reports of the United Nations Framework Convention on Climate Change (UNFCCC). The NFI covers all forests and the information has been used by all ownership groups for justifying and calibrating their own results. It serves as a central information source and tool for use in forestry, the forest industry and forest environment decisions and policy making.

The sampling design and plot and stand-level measurements have been changed in the course of time to respond to contemporary requirements and to optimize the use of the available resources.

The sampling system in the First National Inventory was line-wise survey sampling, introduced by Professor Yrjö Ilvessalo (Ilvessalo 1927). The line interval was 16 kilometres in most parts of the country, but for error estimation purposes, an interval of 13 kilometres was used in one province and 10 kilometres in the Åland

A. Kangas and M. Maltamo (eds.), Forest Inventory – Methodology and Applications, 179–194.

Islands. Plot measurements were carried out in line strips of width 10 metres. The plot length was 50 metres and the interval between plots 2 km. Similar sampling systems with different sampling intensities were employed in the following three inventories up to 1963.

Detached tracts have been employed instead of continuous lines since the fifth inventory (1964-1970) (Kuusela and Salminen 1969). This design is statistically more effective and was also favoured by social developments and the improved road network. At the same time, the inventory became a continuous operation and proceeded by regions from south to north. The fixed-sized sample plots were also changed to Bitterlich plots (angle gauge plots, or PPS sampling, the size being determined by the basal area of a tree at breast height). A new feature in the 5th, 6th and 7th inventories was the use of aerial photographs in Northern Finland (Poso 1972, Poso and Kujala 1971). Two-phase stratified sampling (stratification based on aerial photographs) was employed in the 5th and 6th inventories and photo interpretation plots in the 7th inventory (Mattila 1985).

The ground sampling intensity has been adapted to the variability in forests, taking into account the necessary budget constraints. The sampling intensity in Northern Finland has thus been lower than that in Southern Finland.

About one fifth of the sample plots have been made permanent since the 8^{th} inventory in Northern Finland (1992-1994), and the establishment of such plots was completed for the entire country in the 9th inventory. The aim is to be able to obtain information of a kind that cannot be derived from temporary plots, e.g. the amount and structure of the drain, detailed changes in land use and other changes taking place, and also to reduce the standard error of some estimates.

The length of each cycle, comprising one complete inventory, has been dependent on the funds granted in the national budget, the smallest areal unit for which results are required and the statistical precision of the estimates that is considered desirable. The first four inventory rotations took about three years each, while the next five took 6 to 9 years each. The rotation will be shortened to 5 years from the 10^{th} inventory, which started in 2004.

The main administrative unit for forestry in Finland is the Forestry Centre district, commonly comprising 0.8 - 5.0 million ha of forest land. The mainland is divided into 13 such districts, with the Åland Islands forming an additional one. The standard error in the estimated growing stock volume for these districts is between 2.7 and 1.9 per cent, and that for the entire country 0.6 per cent (Tomppo et al. 1997, 1998, 2001).

Forest statistics for small areas have been computed since 1990 using satellite images and digital map data, e.g. land use data, elevation data and soil data, in addition to field measurements. The role of this multi-source technique is to be able to produce geographically localized information for areas smaller than is possible using field data only, e.g. for individual municipalities, which in Southern Finland typically have an area of some 10 000 ha. The image analysis methods have been chosen in such a way that estimates for all the variables considered in the inventory can be computed for each pixel. The entire country has been processed two and a half times by the method (up to the end of 2004).

The method is described in Chapter 12, and related methods for removing errors caused by errors in the digital input maps in Chapter 13. This chapter describes the field sampling system used in the 9th National Forest Inventory and the relevant calculation methods.

11.2 FIELD SAMPLING SYSTEM USED IN NFI9

The sampling unit used in the ninth inventory rotation, in the years 1996-2003, was a cluster, also referred to as a tract. The sampling design was adapted to the variability in the forests, the distances between two tracts varying from 6 km x 6 km in the southernmost part of the country to 10 km x 10 km in Lapland. The NFI9 sampling designs in the southernmost part of the country, Central Finland and Northern Finland are shown in Figure 1 (Figure 1a, 1b and 1c). The distances between clusters were 10 km x 10 km in the municipality of Kuusamo and in the southern part of Lapland and 7 km x 7 km elsewhere in Northern Finland.

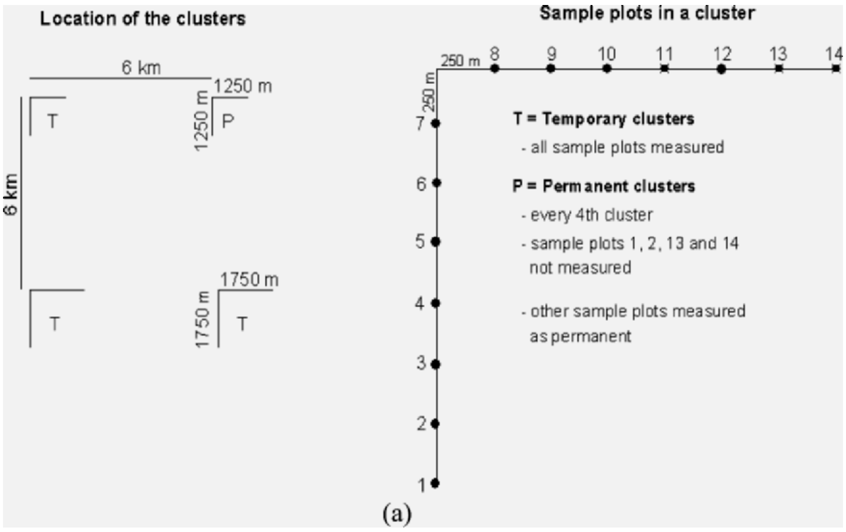
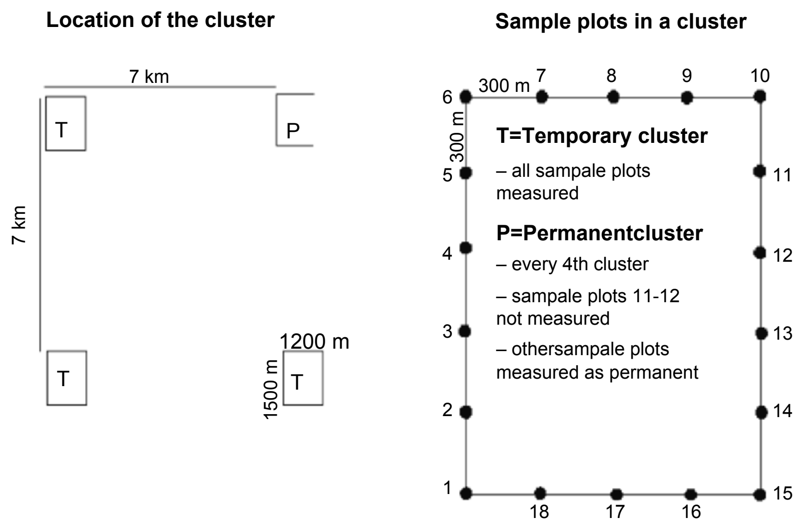
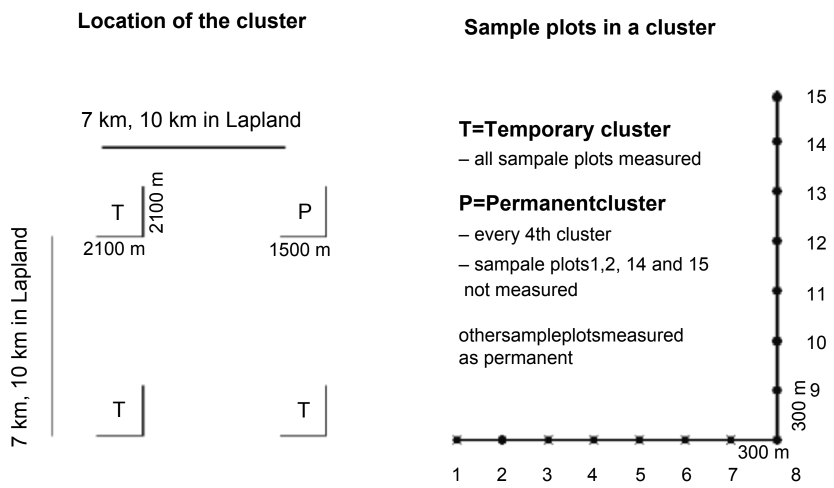


Figure 1. Field sampling designs used for the ninth National Forest Inventory in the southernmost part of Finland (a), in Central Finland (b) and in Northern Finland (c), except for the three northernmost municipalities, where two-phase stratified sampling was employed.


Location of the cluster
Sample plots in a cluster
7 km
7 km
T
P
T
T
1200 m
1500 m
300 m
300 m
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
T=Temporary cluster
– all sampale plots measured
P=Permanentcluster
– every 4th cluster
– sampale plots 11-12 not measured
– othersampale plots measured as permanent

(b)


Location of the cluster
Sample plots in a cluster
7 km, 10 km in Lapland
7 km, 10 km in Lapland
T
P
T
T
2100 m
2100 m
1500 m
T=Temporary cluster
– all sampale plots measured
P=Permanentcluster
– every 4th cluster
– sampale plots1,2, 14 and 15 not measured
othersampleplotsmeasured as permanent
300 m
300 m
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

(c)

Satellite image-based digital volume maps and sampling simulations were employed to evaluate different sampling designs. For each design tested, 1000 samples were chosen and standard deviations for the mean volume computed (Henttonen 1991) and assumed to represent the standard error in mean volume. Another quite important aspect was that a sampling unit (cluster) should represent one day's work on average. It was found that the 'optimum' design depended on the distribution of forest land and the heterogeneity of the forests, for instance, and therefore varied from south to north and from east to west. The sampling intensity was fitted to the spatial variation in forests throughout the whole country, being lower in the north than in the south.

The two-phase stratified sampling applied to the area of the three northernmost municipalities was based on three variables: 1) the per cent of waste land (e.g. open bogs and very poor mineral sites like open rocks), 2) the volume of growing stock and 3) on predicted cumulative day-time temperature. The two first variables were predictions of multi-source forest inventory in a form of thematic maps.

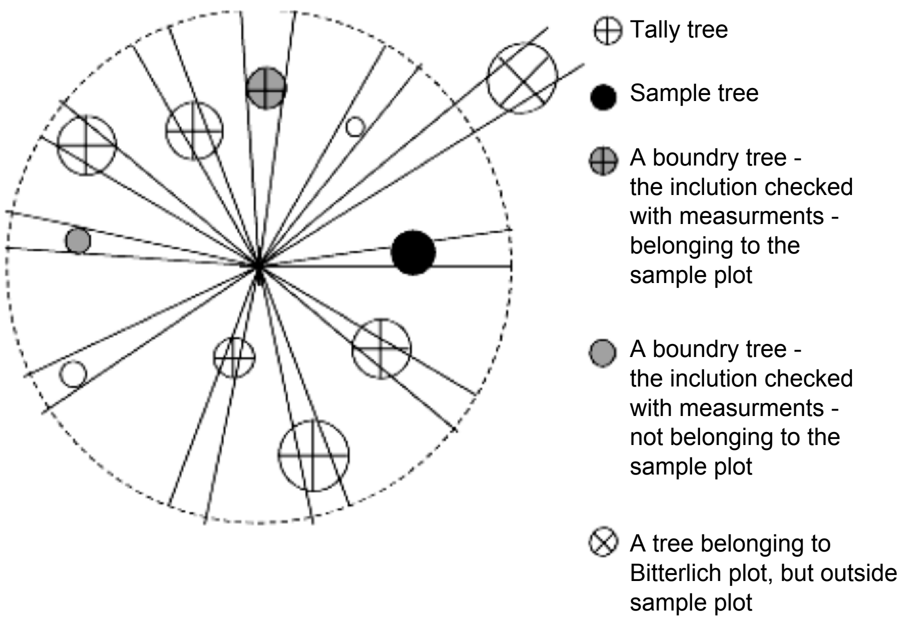


Figure 2. A sample plot as used in NFI9. The maximum radius for trees to be counted was 12.52 m in Southern Finland (q=2) and 12.45 m in Northern Finland (q=1.5). Every 7th tree is measured as a sample tree. The trees are counted by crews, starting at the beginning of the field season.

The sample plot was a Bitterlich plot (angle-gauge plot) and the tally trees were selected with a relascope, the basal area factor (BAF) being 2 in Southern Finland and 1.5 in Northern Finland. The maximum radius was 12.52 m and 12.45 m, respectively (corresponding to breast height diameters of 34.5 cm and 30.5 cm, respectively). Where a relascope could not be used for judging inclusion reliably, this was checked by measuring the distance and diameter of the tree at a height of 1.3 m. Reducing the radius of a sample plot detracted very little from the reliability of the estimates, but it did ease the amount of fieldwork noticeably in some cases, as the number of divided sample plots (i.e. sample plots belonging to two or more stands or strata) decreased. The use of maximum distance may also have reduced errors caused by possible unobserved trees, usually located a long distance from the plot centre and behind other trees. Every 7th tally tree was measured as a sample tree, see Figure 2.

In the Finnish NFI schema forestry land is divided into productive forest land, poorly productive forest land, unproductive forest land (also called waste land) and forestry roads (for definitions, see Kuusela and Salminen 1969). Note that the national definitions of both forest land and poorly productive forest land deviate from the definitions of forest land and other wooded land of the FAO (2001), although the FAO definitions are currently applied in parallel with the national definitions in the Finnish NFI. The main tree species in the Finnish forests are Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.), birch (*Betula* spp.), aspen (*Populus tremula* L.) and alder (*Alnus* spp.). Some hardwood species such as oak (*Quercus robur*) are common locally in the extreme south of the country.

The number of field plots on land in the 9th Finnish National Forest Inventory was 81 249 in the entire country, of which 67 264 were on forestry land, 62 266 on forest land and poorly productive forest land, and 57 457 on forest land alone. Note that the land area and water area by municipalities are assumed to be known and the figures are based on the statistics of Land Survey Finland (Finlands ... 2003). The field plots were geolocated with a GPS system, and trees were measured on those plots which contained forest land and/or poorly productive forest land.

11.3 ESTIMATION BASED ON FIELD DATA

The NFI results can be divided into area, volume and increment estimates. The NFI plots cover the entire land area of the country and its waterways, so that the inventory produces area estimates not only for forestry land strata but for all land use classes. Forest land and forestry land are divided into sub-categories on the basis of site, ownership, silviculture and cutting regimes, treatments needed and growing stock, e.g. tree species composition, age and mean diameter of trees.

11.3.1 Area estimation

Area estimation is based on the total land area and inland water areas which are known or assumed to be error-free, and on the number of centre points of the plots. In brief, the area estimate of a land stratum is the number of plot centres in the stratum divided by the total number of plot centres and multiplied by the known land area. Due to the fact that the number of plot centres on land is a random variable (depending on the design), the area estimators are ratio estimators (Cochran 1977)

$$a_s = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i} A = \frac{\bar{y}}{\bar{x}} A \,, \tag{11.1}$$

where a_s is the area estimate of the stratum s, A the land area on the basis of the official statistics of the Finnish Land Survey (Finlands ... 2003), y_i is 1, when the centre point of the plot belongs to the stratum in question and 0 otherwise, x_i is 1 when the centre point is on land and 0 otherwise, and n is the number of centre points on land (see Tomppo et al. 1997, 1998, 2001). Examples of land strata are forest land, spruce-dominated forest land and forest land thinned during the last ten years.

11.3.2 Volume estimation

Volume in the Finnish NFI means tree stem volume over bark (that is with bark), from above the stump to the top of the tree, excluding branches. All trees of height at least 1.3 m (i.e., breast height diameter > 0 cm) are included in the volume estimate. The volume estimators are ratio estimators in a similar manner to the area estimators (Eq. 11.1). Briefly, to obtain the mean volume for a given stratum, the mean volumes of all trees belonging to that stratum are summed and divided by the number of field plot centre points in the stratum. The mean volume of a tree means here the volume per hectare represented by the tree (see formulas 11.3a and 11.3b). The indicator variable y_i in the nominator of (11.1) is replaced with the mean volume represented by a tree, or the mean volume of timber assortment class of interest represented by the tree, on field plot i when computing mean volume or total volume estimates. For total volumes, the mean volumes have to be multiplied by the area estimate for the stratum in question.

The mean volumes (m^3/ha) and total volumes (m^3) are estimated as follows:

1. Volumes and volumes by timber assortment classes are predicted for sample trees (every 7th tally tree) using volume functions and taper curve models

(Laasasenaho 1982) and sample tree measurements (see Kuusela and Salminen 1969, Tomppo et al. 1997, 1998).

2. The volumes of tally trees are predicted by strata using the volume predictions for the sample trees and measured and observed tally tree, stand and site variables.
3. Mean volumes are tabulated by computation strata.
4. Area estimates are calculated for the volume strata.
5. Total volumes are tabulated by computation strata.

11.3.2.1 Predicting sample tree volumes and volumes by timber assortment classes

The volumes of the sample trees are predicted using the volume functions of Laasasenaho (1976, 1982), the parameters of the functions having been estimated for the following tree species or tree speices: pine, spruce, birch, aspen, alder, and Siberian larch, (*Larix siberica*, Ledeb.). Models for pine or birch are used for other coniferous and broad-leaved tree species respectively. The explanatory variables of the models are (measured) diameter at breast height $d_{1.3}$, (measured) upper diameter d_6 (for trees of height at least 81 dm) and (measured) height h. The model is thus of the form:

$$\text{current volume over bark } v_{ob,0} = f(\text{tree species, } d_{1.3}, d_{6.0}, h) .$$

Separate unpublished models of small trees are employed for trees shorter than a certain tree species-specific threshold, i.e. pine 4.5 m, spruce 3.5 m, birch 6.5 m, aspen 5.0 m and alder 4.0 m.

The volumes of timber assortment classes can also be predicted for sample trees using the taper curve models of Laasasenaho (1982). The explanatory variables are $d_{1.3}$, d_6 (for trees of height at least 81 dm), height h and lengths of the stem parts of different timber assortment classes.Account is also taken of the minimum length requirements, quality requirements and relative unit prices of the timber assortments. A tree stem is assumed to be cut into timber assortments in such a way as to maximize its value. The relative unit price classes are: saw timber (class I) 3, saw timber (class II) 2.5, saw timber (class III) 2 and pulp wood 1.

11.3.2.2 Predicting volumes for tally trees

When using Bitterlich sampling (angle-gauge plots), each tree represents the same basal area per hectare. It is thus convenient to work with quantities called form heights rather than single tree volumes when computing mean volumes or total volumes. Form height is defined as

$$fh = \frac{v}{g}, \tag{11.2}$$

where v is the volume of a tree stem (or the volume of a timber assortment in a tree) and $g = \pi d_{1.3}^2 / 4$ is the intersectional area of the tree at breast height.

Form heights are predicted for tally trees by the non-parametric k nearest neighbour (k-NN) estimation method. For each tally tree whose volumes are to be predicted, the k nearest sample trees are sought, the distance metric applied being Euclidean distance in the Cartesian product space of tree-level variables, tree species, $d_{1.3}$, and tree quality class, and stand-level variables, region code, cumulative day time temperature, site fertility class and stand establishment type. The weighted average of form heights (11.2) for the k nearest sample trees is then used as a predictor for the form height of the tally tree. The weight is the squared diameter of the sample tree. A similar method is employed when predicting the form height of a timber assortment. Only the variables $d_{1.3}$ and tree species group (coniferous vs. non-coniferous) are employed for trees with $d_{1.3}$ < 2 cm, due to the small number of sample trees of a small diameter.

In the case of small strata, e.g. exceptionally thick trees on poor sites, the distances from the nearest neighbours may be high, that is, similar sample trees are rare or do not exist in the current inventory for the region. A priori form height prediction is used as additional information when predicting volumes for these trees, the a priori information being the predicted volume as a function of $d_{1.3}$ and tree species group. The prediction models employed have been estimated using sample trees from neighbouring regions and/or sample trees from the previous inventory.

In total, 18 prediction models are estimated for each region (6 tree species or species groups multiplied by three form height models, corresponding to total volume, saw timber volume and waste wood volume). Sample trees from the previous inventory are not used in estimating form height models for timber assortments, due to changes in the timber quality requirements between inventories. The final form height prediction is a weighted average of the k-NN prediction and a priori prediction (Tomppo et al. 1998).

11.3.3.3 Computing volumes for computation units

The mean volume (m^3/ha) represented by a tree identified using angle-gauge sampling is

$$u = qfh. \tag{11.3a}$$

The maximum distance from the plot centre assigned to tally trees is 12.52 m in Southern Finland, where q = 2, and 12.45 m in Northern Finland, where q = 1.5. Trees thicker than 34.5 or 30.5 cm, respectively, are counted in a fixed-radius plot of area $a = \pi R^2$, where R is the maximum distance. The mean volume represented by this type of tree is

$$u = \frac{g}{a} f h, \qquad (11.3b)$$

where g is the basal area of the tree, $g = \pi d_{1.3}^2 / 4$.

The mean volume (m^3/ha) of a stratum is estimated using the formula

$$v_s = \frac{\sum_{i=1}^{n} \sum_{k=1}^{n_i} u_{i,k}}{\sum_{i=1}^{n} x_i}, \qquad (11.4)$$

where v_S is the estimate for the mean volume of a stratum S , n is the number of centre points of plots on land in the region, $u_{i,k}$ is the mean volume represented by tree k in stratum S on plot i, n_i is the number of trees in stratum S on plot i and x_i is 1 if the centre of plot i belongs to stratum S and 0 otherwise.

The total volume estimate is

$$V_S = v_S a_S \qquad (11.5)$$

where a_S is the estimate for the area of the stratum.

Note that the method takes into account plots shared between two or more calculation strata, so that trees belonging to the stratum in question in parts of a plot that do not include the centre are also included in the sum in formula (11.4). It is assumed in volume estimation that the plot parts are distributed purely randomly between any two arbitrary strata s_1 and s_2. That is, for plots whose centre points belong to s_2 , the expected area of the plot parts belonging to s_1 is the same as the area of the plot parts belonging to s_2 whose centre points belong to s_1.

11.4 INCREMENT ESTIMATION

Volume increment in the Finnish NFI means the increase in tree stem volume over bark, from above the stump to the top of the tree. The annual volume increment is calculated as an average over five years, based only on full growing seasons, assuming that tree growth has finished by August 1. Thus the increments in the five years preceding the inventory year are used for trees measured before August 1, and those in the inventory year and the four preceding years for trees measured on or after August 1.

The phases in calculating the volume increment of a stratum are:

1. prediction of the annual increments in sample trees
2. calculation of the average increments for sample trees by diameter classes (at 1 cm intervals) and by strata, e.g. land use classes, site fertility classes and tree species groups

3. calculation of the total increment for survivor trees in each stratum by diameter classes, by multiplying the average increment for trees in each diameter class by the number of tally trees in that class and summing the increments over the diameter classes
4. calculation of the final increment adding the drain increment to that for the survivor trees.

The need for the last phase is explained below. The sample tree variables employed in the volume increment calculation, in addition to those required in the volume calculation, are: bark thickness, diameter increment in five (full growth) years at a height of 1.3 m (above ground) and height increment. The height increment is measured only for coniferous trees, while that for broad-leaved trees is predicted by means of models (Kujala 1980).

The change in bark thickness must be taken into account in volume calculations, and this is done by introducing the ratio 'volume over bark divided by the basal area under bark (at a height of 1.3 m)'. It is assumed that the change in this ratio is parallel to the average change calculated from a large set of sample trees (Kujala 1980).

To present the calculation of volume increments more formally, the following variables and notations are introduced (cf. Kujala 1980).

d = diameter of tree at height 1.3 m in the inventory year
d_6 = diameter of tree at height 6 m in the inventory year
b = double bark thickness
h = height of tree in the inventory year
i_d = diameter increment
i_h = height increment
h_{-5} = height of tree 5 years before the inventory year
$g_{ub,0}$ = basal area of tree under bark in the inventory year (= $\pi(d-b)^2/4$)
$g_{ub,-5}$ = basal area of tree under bark 5 years before the inventory year (= $\pi(d-i_d-b)^2/4$)
$v_{ob,0}$ = volume of tree over bark in the inventory year
$v_{ob,-5}$ = volume of tree over bark 5 years before the inventory year
i_v = annual volume increment
r_0 = $v_{ob,0}/g_{ub,0}$, current volume over bark divided by current basal area under bark
r_{-5} = $v_{ob,-5}/g_{ub,-5}$, volume over bark 5 years ago divided by basal area under bark 5 years ago
$\hat{r}_0$ = predicted ratio of current volume over bark to current basal area under bark'
$\hat{r}_{-5}$ = predicted ratio of volume over bark 5 years ago to basal area under bark 5 years ago

The predicted ratios $\hat{r}$ are calculated using models for r based on NFI6 data for Southern Finland by tree species covering over 40 000 sample trees. The only explanatory variable is tree height, h. The ratio r may be regarded as a form height when using the basal area under bark. For a discussion of the reliability of this approach, see Kujala (1980).

1. Predicting the annual increment in a sample tree

1a. For a sample tree, take the current volume over bark as presented in 11.3.2.1. i.e.

$$v_{ob,0} = f(\text{tree species, } d_{1.3}, d_{6.0}, h) \ . \qquad (11.6).$$

1b. Calculate the ratio

$$r_0 = v_{ob,0} / g_{ub,0}. \qquad (11.7)$$

1c. Calculate the predicted ratios $\hat{r}_0$ and $\hat{r}_{-5}$ using the estimated models.
1d. Define

$$r_{-5} = r_0 - (\hat{r}_0 - \hat{r}_{-5}) \ . \qquad (11.8)$$

1e. Define

$$v_{ob,-5} = r_{-5} \times g_{ub,-5} \ . \qquad (11.9)$$

1f. Define

$$i_v = (v_{ob,0} - v_{ob,-5}) / 5 \qquad (11.10)$$

It is assumed that for each individual tree, the derivative of the ratio r, dr/dh, is same as that for the ratio predicted by the model. The bark of trees growing on poor sites is usually thicker than that of trees growing on fertile sites, which will increase the value of r. On the other hand, the form height of trees on poor sites is usually lower than that of trees on fertile sites. These facts cancel each other out to some extent, making the change in r as a function of h almost a tree species-specific constant.

Example 11.1 (Kujala 1980).

For pine, $\hat{r} = 0.39h + 2/(h-1.3) + 0.77\sqrt{h-1.3}$ (omitting a constant 0.39).

Let us take a pine tree with $d = 16$ cm, $d_6 = 11$ cm, $h = 12$ m, $b = 15$ mm, $i_d = 20$ mm and $i_h = 1.9$ m. Then $g_{ub,0} = 0.01651$ m^2, $g_{ub,-5} = 0.01227$ m^2 and $h_{-5} = 10.1$ m. From the taper curve models, $v = 0.1207$ m^3. Hence, $r = 7.309$. From the pine model for $\hat{r}$, $\hat{r}_0 = 7.386$, and $\hat{r}_{-5} = 6.450$. By formula (11.8) $r_{-5} = 6.373$, and thus by formula (11.9) $v_{ob,-5} = 6.373 \times 0.01227$ m^3 = 0.0782 m^3. Thus $i_v = 0.0085$ m^3.

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2. Calculation of average increments in sample trees by diameter classes

The increment strata are composed in such a way that it can be assumed that the expected volume increase by diameter class is the same for each tree in a stratum. Thus the land use class (forest land, poorly productive forest land), main site class (mineral soil, spruce mire, pine mire), site fertility class and cumulative daytime temperature are all stratification factors in addition to tree species. The increment in tally trees of a diameter class *d* is the average increment in the sample trees multiplied by the number of tally trees, i.e.

$$i_{v,s,d} = n_{t,S,d} \times \bar{i}_{v,s,d} \, , \qquad (11.11)$$

where $n_{t,S,d}$ is the number of tally trees in stratum S and diameter class d and $\bar{i}_{v,s,d}$ the average increment in sample trees in stratum S and diameter class d.

3. Total increment in survivor trees

The total increment is summed over the diameter classes and calculation strata:

$$i_v = \sum_s \sum_d i_{v,s,d} \, . \qquad (11.12)$$

4. Total increment and increment in the drain

Only increments in trees that have survived until the inventory time can be measured. To calculate the total increment over the five-year calculation period, the increments in the trees that have either been cut or have died naturally during the calculation period have to be added to the increment for the survivor trees. If a tree was cut two years before the inventory time, for instance, the increment in the first three years of the period has to be taken into account.

The total drain consists of the following components

1) cutting removals reported by forest industry companies,
2) non-commercial roundwood removals, e.g. contract sawing and fuel wood used in dwellings,
3) estimates of harvesting losses, including those arising from silvicultural measures, based on a special study by the Finnish Forest Research Institute,
4) volume of unrecovered natural losses (currently 2.5 mill. m^3).

It is assumed that the percentage increment in trees that have subsequently been cut or have died is on average 70% of that in survivor trees. The fact that drain statistics are compiled by calendar years whereas inventory measurements in a region are carried out during the growing season, often partly before August 1 and partly on or after that date in the same region, has to be taken into account when calculating the increment represented by the drain, which is done by dividing the inventory region into two sub-regions on an area basis. The tree species strata for drain statistics are pine, spruce and broad-leaved trees. The increment for a tree species is

$$0.7\frac{i_v}{v}\sum_j p_{y_j} q_{y_j} \ , \qquad (11.13)$$

where i_v is the increment in the survivor trees of that species (tree species group), v is the volume of the survivor trees of that species (tree species group), p_{y_j} , j=1,2 is the proportion of that land area measured before August 1 in the inventory year (j = 1) or from August 1 onwards (j=2), q_{y_j}, j=1,2 is a function of the annual drain volumes $v_{dr,t}$ as follows:

$$q_{y1} = (v_{dr,t-5} + 3\ v_{dr,t-4} + 5\ v_{dr,t-3} + 7\ v_{dr,t-2} + 9\ v_{dr,t-1} + 5\ v_{dr,t})/2, \qquad (11.14)$$

$$q_{y_2} = (v_{dr,t-4} + 3\ v_{dr,t-3} + 5\ v_{dr,t-2} + 7\ v_{dr,t-1} + 4\ v_{dr,t})/2,$$

$5_{vdr,t-k}$, $k = 0,...5$, is the volume of the drain in year t-k and t is the inventory year (Salminen 1993).

The total increment is the sum of the increment in survivor trees and the increment in the drain (Kuusela and Salminen 1969).

11.5 CONCLUSIONS

The methods employed for calculating the results of the Finnish 9th National Forest Inventory, together with the field measurements and a brief account of the sampling design, have been described in this chapter . The sampling design was decided upon and modified on the basis of experiences and information gathered from the previous inventories. Sampling simulation studies were conducted in all the inventory regions to optimize the design, given acceptable maximum standard errors in the mean volume and total volume of growing stock and estimated measurement costs.

The estimation methods had also gained their current form during previous inventories and through experiences accumulating since the 1920s.

Some basic facts affecting the estimation methods are that NFI9 was based on temporary plots (permanent plots were established in the course of that survey, or in NFI8 in the case of Northern Finland), the land area is assumed to be known and the tally tree plot is an angle-gauge plot (Bitterlich plot). Both the area and volume estimators are ratio estimators. Area estimation is based on the number of centre points of plots.

In volume estimation all the trees belonging to the stratum in question are counted, including trees on parts of a plot that do not include the centre point. All trees are assigned to calculation strata in the field measurements. The sum of tree level volumes per hectare is divided by the area estimate for the stratum concerned. The area estimates are also based on the number of centre points in the volume calculations. This method avoids time-consuming-measurements of the areas of parts of plots in the field and produces statistically unbiased estimates if the boundaries between the calculation strata intersect the field plots purely at random. That is, for the, the area of the parts of plots whose centre points belong to s_2 that belong to s_1 is the same as the area of parts of plots with centre points belonging to s_1 that themselves belong to s_2.

Measurement of the areas of parts of angle-gauge plots would be very difficult or impossible in practice. Note that this method for handling divided plots is also applicable to the case of fixed-radius field plots.

Increment estimation is based on increment borings and height increment measurements performed on sample trees (height increment models in the case of broad-leaved trees). In principle, this method corresponds to the use of permanent plots for increment estimation but produces estimates with a lower standard error than the method which uses volume differences on permanent plots, due to the fact that errors in diameter measurements are usually greater than errors in the measurement of diameter increment cores. NFI also produces information about growth variation (Henttonen 2000), but the increment estimates given in normal publications are presented without growth variation corrections.

NFI10 began in 2004 and is proceeding in a different way from NFI9, with one fifth of the plots in the entire country being measured each year. Thus country-level estimates can be updated annually and regional-level estimates within 2-3 years of the start of the survey. A new estimation method is under development which takes into account the fact that both temporary and permanent plots are used (roughly one fifth of the plots are permanent).

Method used for estimating the standard errors in the area and volume calculations is based on the ideas presented by Matérn (1960) and is described and discussed in detail in the article by Heikkinen in this book, Chapter 10.

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