The Finnish National Forest Inventory

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Abstract.—The National Forest Inventory (NFI) of Finland has produced large-area forest resource information since the beginning of 1920s (Ilvessalo 1927). When the 10th inventory (NFI10) started in 2004, the design was changed and the rotation shortened to 5 years. Measurements are done in the entire country each year through measuring one-fifth of the plots. About one-fifth of all plots are measured as permanent. Using field data only, it is possible to compute reliable estimates for large areas, the minimum size of the area is typically some hundreds of thousands of hectares. In practical forestry, estimates are also often required for smaller units such as municipalities with typical areas of tens of thousands of hectares. This is possible only if ancillary data are used in addition to sparse field data. The Finnish multisource NFI uses satellite images and digital map data, in addition to field data, and produces estimates for small areas and wall-to-wall maps. Information from the Finnish NFI has traditionally been used in large area forest management planning, such as planning regional and national level cutting, improving silviculture and forest regimes, making decisions concerning forest industry investments, and providing a basis for forest income taxation. The NFI also provides forest resource information for national and international forest statistics and processes such as the United Nations Food and Agriculture Organization's (FAO) Forest Resource Assessment process and the Land Use, Land-Use Change and Forestry reporting of the United Nations Framework Convention on Climate Change.. Sampling designs for the ninth inventory rotation (NFI9)—conducted from 1996 to 2003—and NFI10 are described, as well as the basic principles of estimation methods based on field data only.

Introduction

The sampling design and plot- and stand-level measurements have been changed over time to respond to contemporary requirements and to optimize the use of the available resources. The sampling system in the first NFI was line-wise survey sampling, introduced by Professor Yrjö Ilvessalo (Ilvessalo 1927). The line interval was 16 km in most parts of the country, but, for error estimation purposes, an interval of 13 km was used in one province and 10 km in the Åland Islands. Plot measurements were conducted in line strips 10-m wide. The plot length was 50 m and the interval between plots was 2 km. Similar sampling systems with different sampling intensities were used in the following three inventories up to 1963. Detached tracts have been used instead of continuous lines since the fifth inventory (1964–1970) (Kuusela and Salminen 1969). At the same time, the inventory became a continuous operation, proceeded by regions from south to north. The fixed-size sample plots were also changed to Bitterlich plots (angle gauge plots, or probability proportional to size sampling, determined the size of the plot based on the basal area of a tree at breast height). A new feature in the fifth, sixth, and seventh inventories was the use of aerial photographs in northern Finland (Poso 1972). Two-phase stratified sampling (stratification based on aerial photographs) was used in the fifth and sixth inventories and photo interpretation plots in the seventh inventory.

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 eighth inventory in northern Finland (1992–94), and the establishment of such plots was completed for the entire country in NFI9. 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

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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 area unit for which results are required, and the statistical precision of the estimates that is considered desirable. The first four inventory rotations took about 3 years each, while the next five took 6 to 9 years each. The rotation was shortened to 5 years starting from NFI10, which started in 2004. The sampling design was slightly modified at the same time.

The main administrative unit for forestry in Finland is the Forestry Center district, commonly comprising 0.8 to 5.0 million ha of forest land. The mainland is divided into 13 such districts, with the Åland Islands forming an additional district. The standard error of the estimated growing stock volume for these districts is between 2.7 and 1.9 percent, and that for the entire country is 0.6 percent (Tomppo *et al.* 1997, 2001; Tomppo 2006).

The information generated by the NFI has traditionally been used for 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 FAO Forest Resource Assessment process and the Ministerial Conference on the Protection of Forests in Europe. 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 reports of the United Nations Framework Convention on Climate Change. 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 policymaking.

Field Sampling System Used in NFI9 and NFI10

The sampling unit used in NFI9 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 by 6 km in the southernmost part of the country to 10 by 10 km in Lapland. The sampling density regions, six regions, together with field plot clusters are shown in figure 1. The NFI9 sampling designs, cluster sizes, and distances between clusters, in the southernmost part of the country, central Finland, north-central Finland, south Lapland, and north Lapland are shown in figure 2 (figs. 2a, 2b, 2c, 2d). The distances between clusters were 10 by 10 km in the municipality of Kuusamo and in south Lapland, and 7 by 7 km elsewhere in north-central Finland.

Figure 1.—*The sampling density regions of the NFI9 and NFI10 with the field plot clusters of NFI9.*

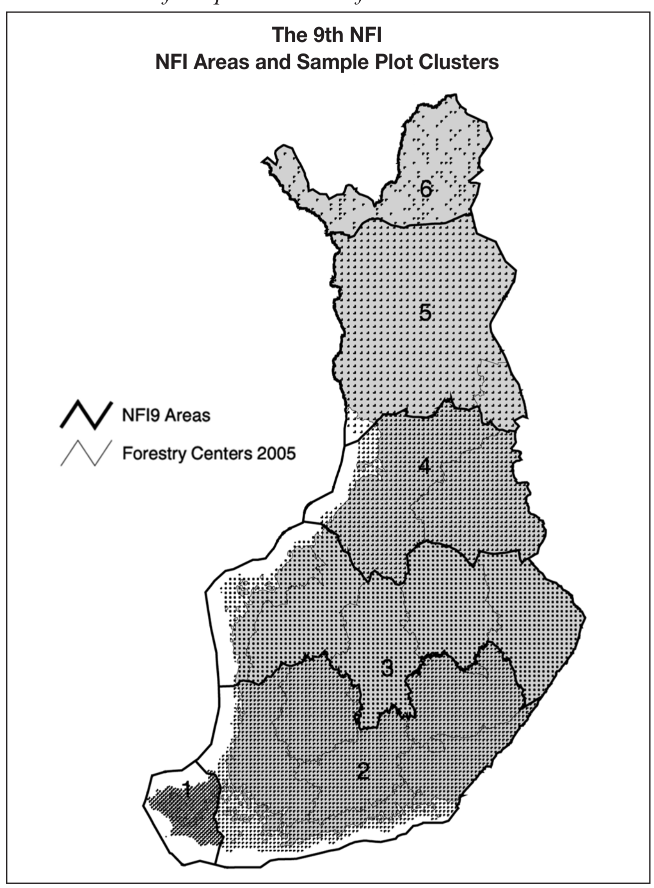
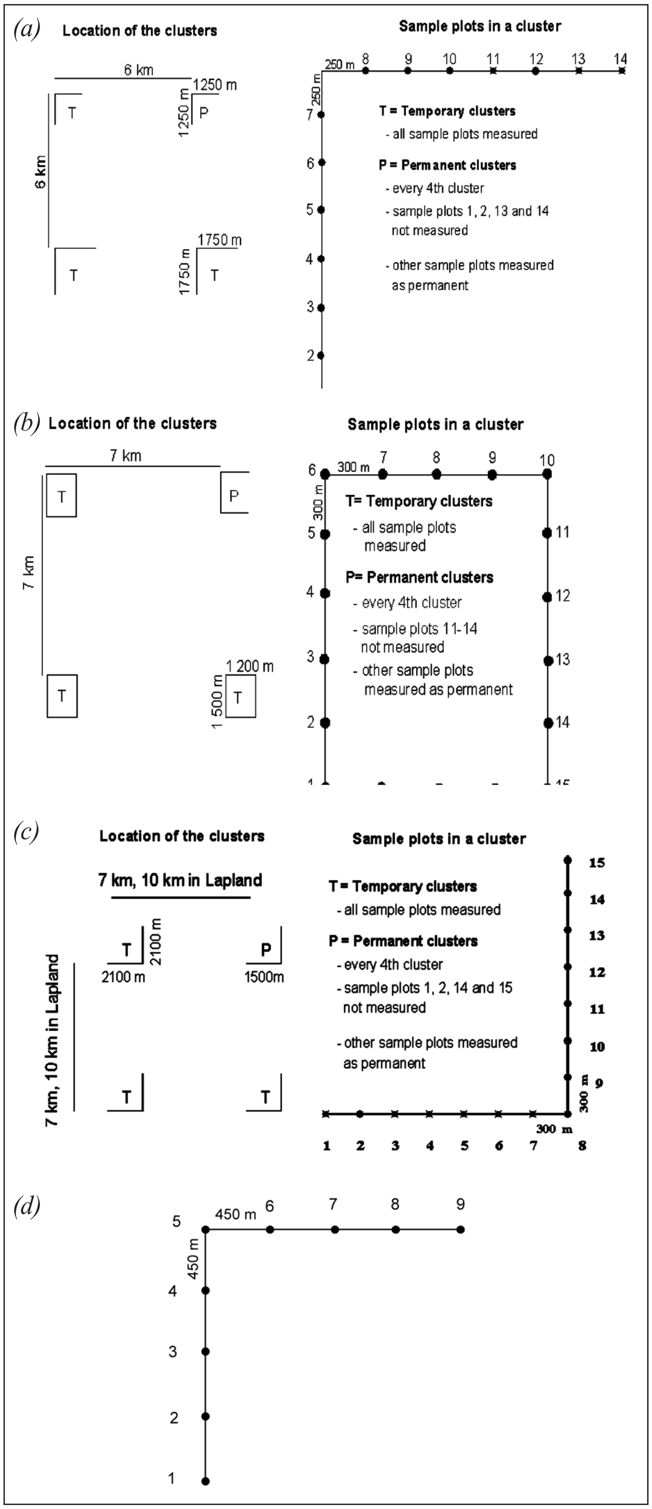


Figure 2.—*Sampling design of the NFI9 in different inventory regions: (a) region 2 (in region 1, the design is same but the distances are 3 by 3 km), (b) region 3, (c) region 4 (in region 5, the design is same but the distances are 10 by 10 km, (d) region 6. Stratified sampling was applied in region 6.*



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

Note that in the estimation, except error estimation, a field plot is a single observation; in the error estimation, a field plot is a cluster.

Satellite image-based digital volume maps and sampling simulations were used to evaluate different sampling designs. For each design tested, 1,000 samples were chosen and standard deviations for the mean volume were 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 1 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 adapted to the spatial variation in forests throughout the whole country, being lower in the north than in the south.

The progress of the inventory was changed somewhat for NFI10 (2004–08). Measuring field plots in the entire country each year was the biggest change compared to the NFI5 - NFI9. One-fifth of the clusters is measured annually. Exceptions are region 1, which was measured in 2007, and region 6, which will be measured next time during NFI11. At the same time, the inventory rotation was shortened to 5 years, a reduction of almost 5 years. Inventory progressed by regions from the fifth inventory (1964–70) until NFI9 (1996–2003). This change makes it possible to compute the basic forest resource estimates annually for the entire country. NFI9 data for permanent plots will also be used in estimation. The method is thus sampling with partial replacement.

The basic principles in sampling designs of NFI10 are similar to those of NFI9. The need to shift the locations of the clusters with temporary plots caused some changes. The clusters with temporary plots were shifted 1 km west and 1 km north in this rotation (fig. 3—figs. 3a, 3b, 3c, 3d). Shortening of the inventory rotation also adds pressure to reduce the number of field plots slightly. New sampling simulation studies were carried out in all parts of the country for the forest area, mean volumes by tree species (m^3/ha), and total volumes (m^3) variables. The numbers of the field plots per cluster in different regions are shown in figure 3.

The sample plot was a Bitterlich plot (angle-gauge plot) in both NFI9 and NFI10. Tally trees are selected with a relascope, the basal area factor being 2 in southern Finland and 1.5 in northern Finland. The maximum radius is 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, inclusion 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 detracts very little from the reliability of the estimates, but it does 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) decreases. The use of maximum distance may also reduce errors caused by possible unobserved trees, usually located a long distance from the plot centre and behind other trees. Every seventh tally tree is measured as a sample tree (fig. 4).

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. 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 used in parallel with the national definitions in the Finnish NFI.

The number of field plots on land in NFI9 was 81,249 in the entire country, of which 67,264 were on forestry land. Of the plots on forestry land, 62,266 were on combined 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 (Land

Figure 3.—*Sampling designs of the NFI10 in different inventory regions: (a) region 2 (in region 1, the design is same but the distances are 3 by 3 km), (b) region 3, (c) region 4 (in region 5, the design is same but the distances are 10 by 10 km,(d) region 6. Stratified sampling will be applied in region 6.*

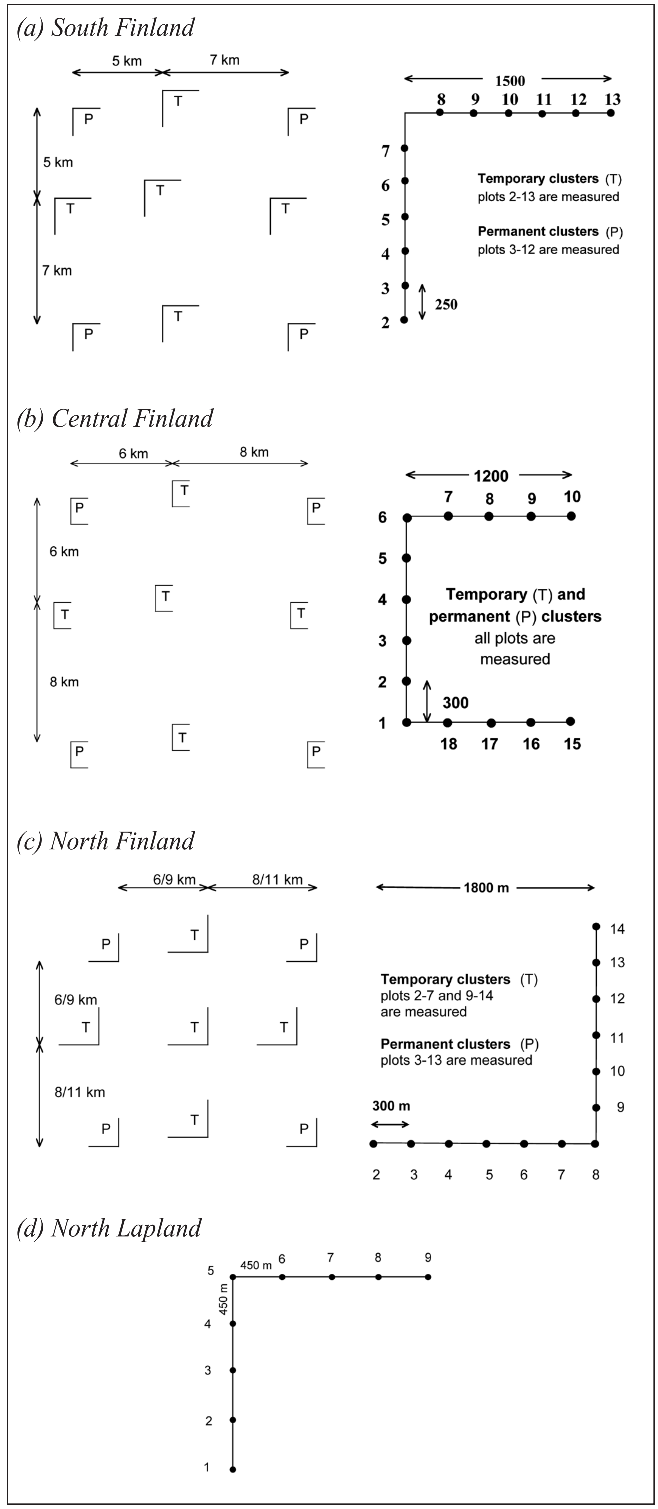
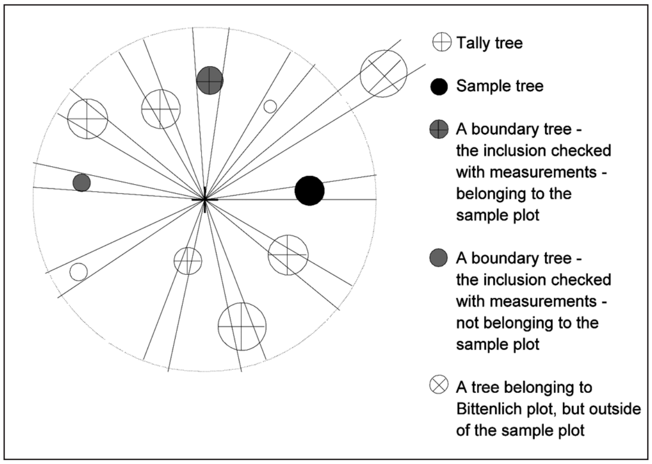


Figure 4.—*A sample plot as used in NFI9. The maximum radius for trees to be counted was 12.52 m in southern Finland (q = 2) and 12.45 m in northern Finland (q = 1.5). Every seventh tree is measured as a sample tree. The trees are counted by crews, starting at the beginning of the field season.*



Survey Finland 2003). The field plots were geolocated with geographic positioning system receivers and trees are measured on those plots that contained forest land and/or poorly productive forest land.

Estimation Based on Field Data

Some basic principles of the estimation in NFI9 are given. The major change in NFI10 and in the following inventories will be the use of permanent plots from earlier rotations and estimation based on framework of sampling with partial replacement. The final estimates are made based on (1) estimates derived from NFI10 data, and (2) estimates derived from NFI9 data and changes on NFI9 and NFI10 data. The two estimates are inversionally weighted proportionally to their estimated variances (Scott 1984, Ranneby 1995). The use of post-stratification based on multisource output map data will also be tested (McRoberts *et al.* 2002).

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 subcategories on the basis of site, ownership, silviculture, and cutting regimes, growing stock and needed treatments (e.g., tree species composition, age, and mean diameter of trees).

Area Estimation

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

$$a_s = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i} A = \frac{\bar{y}}{\bar{x}} A, \qquad (1)$$

where:
a_s is the area estimate of the stratum s, A is the land area on the basis of the official statistics of the Finnish Land Survey (Land Survey Finland 2003), y_i is 1 when the center point of the plot belongs to the stratum in question and 0 otherwise, x_i is 1 when the center point is on land and 0 otherwise, and n is the number of center points on land (Tomppo *et al.* 1997, 1998, 2001; Tomppo 2006). Examples of land strata are forest land, spruce-dominated forest land, and forest land thinned during the past 10 years.

Volume Estimation

Volume in the Finnish NFI means tree stem volume over bark (i.e., with bark) from above the stump to the top of the tree, excluding branches. All trees of at least 1.3 m of height (i.e., breast height diameter > 0 cm) are included in the volume estimate. The volume estimators are ratio estimators similar to the area estimators (eq. 1). Briefly, to obtain the mean volume for a given stratum, the mean volumes of all trees belonging to that stratum are added and divided by the number of field plot center points in the stratum. The mean volume of a tree is the volume per hectare represented by the tree (see equations [3a] and [3b]). The indicator variable y_i in the numerator of equation (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 seventh tally tree) using volume and taper curve models (Laasasenaho 1982) and sample tree measurements (Tomppo *et al.* 1997, 1998, Tomppo 2006).
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.

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

$$fh = \frac{v}{g}, \tag{2}$$

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

$$u = q\, fh. \tag{3a}$$

The maximum distance from the plot center 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

$$u = \frac{g}{a} fh, \tag{3b}$$

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 in NFI9 using the formula

$$v_S = \frac{\sum_{i=1}^{n} \sum_{k=1}^{n_i} u_{i,k}}{\sum_{i=1}^{n} x_i}, \tag{4}$$

where v_s is the estimate for the mean volume of a stratum *S*, n is the number of center 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, x_i is the number of trees in stratum *S* on plot i, and x_i is 1 if the center of plot *i* belongs to stratum *S* and 0 otherwise. The total volume estimate is

$$V_S = v_S a_S \tag{5}$$

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 center are also included in the sum in equation (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 centerpoints 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 center points belong to s_1.

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 5 years, based only on full growing seasons, assuming that tree growth has finished by August 1. Thus the increments in the 5 years preceding the inventory year are used for trees measured before August 1, and those in the inventory year and the 4 preceding years for trees measured on or after August 1.

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

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 details are given in Tomppo (2006) and Kujala (1980).

Conclusions

The sampling designs of NFI9 and the current NFI10 are described, as well as basic estimation principles. The NFI was changed from regionwise, progressing to a rolling system for NFI10, causing some minor changes in the design as well.

The sampling design was selected on and modified on the basis of experience 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 gained their current form during previous inventories and through experience 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). In both NFI9 and NFI10, 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 center points of plots.

In volume estimation, all trees belonging to the stratum in question are counted, including trees on parts of a plot that do not include the center point. All trees are assigned to calculation strata in the field measurements. Increment estimation is based on increment borings and height increment measurements performed on sample trees (i.e., height increment models in the case of broadleaved trees).

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 region-level estimates updated within 2 to 3 years of the start of the survey. An estimation method sampling with partial replacement will be used. The 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 by Heikkinen (2006).

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