RESOURCE ASSESSMENT

Contents

Forest Resources

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Introduction

The term 'inventory' means the preparation of a detailed list of articles according to their properties. Similarly, forest inventory means tabulated, reliable, and satisfactory tree information related to the required area unit. An essential feature is the assessment of the area and quality of each unit. The principal purpose of forest inventories has been to provide accurate information for sound planning and management of resources and for the planning of forest industry investments and nature conservation. Accordingly, optional cutting possibilities with future forest development scenarios have been computed on the basis of inventory results. These scenarios have formed the basis for forest policy and forest utilization.

The needs for information in forestry have increased during the last decades because of the awareness of forest health status, particularly since the beginning of the 1980s, and the status of biological diversity, as well as the recognition of the role of forests in reducing the effects of global warming. At the same time, the pressure to increase timber consumption is increasing in some regions of the world. Therefore, reliable forest information is important to plan the sustainable use of forests.

The Food and Agricultural Organization of the United Nations (FAO) and International Union of Forest Research Organizations (IUFRO) collect and agree globally accepted concepts and definitions used in forest inventories.

FAO has also collected global-level forest resource information since 1947. Since the beginning of the 1950s, various regional and global surveys have been conducted every 5–10 years. As knowledge on the forest resources has improved at national levels and as technology has advanced, the Global Forest Resources Assessments have increased in breadth and quality. Forest Resource Assessment 2000 (FRA 2000) is so far the most comprehensive in terms of the number of references used and information analyzed on forest cover, forest state, forest services, and nonwood forest products (NWFP). FRA 2000 applies for the first time a single technical definition of forest at the global level, based on 10% crown cover.

There are also several types of forest inventories, such as operational, management, and national forest inventory. The information from operational and management inventories is used to make short- and long-term plans for the management of specific forest ownership while national forest inventories are used as the information basis for national forestry policy, forestry programs, and strategic planning of forestry and forest industry. Forest inventory is considered here from the point of view of national forest inventory. There are several definitions for the term 'forest inventory' in the forest inventory literature. A modern national forest inventory could be defined as follows:

> *Forest inventory is a procedure involving planning of inventory design, data collection, data analysis and reporting about forest resources of a large forested area or entire country. It is designed to insure continuous flow of information about the current status and rate of changes over time about forest resources and the characteristics of the land area on which trees are growing.*

Forest inventory information is related to administrative or other area units and presented in the form of tables and forest maps together with reliability assessments. Basic information is timber quantity and quality by tree species and by tree size as well as tree growth, mortality, and removal by harvest. Inventories have also provided information about land use, site quality, vegetation cover, description of topography, ownership and protection patters, accessibility, transportation facilities, accomplished and needed silvicultural and cutting regimes, and forest damage. When needed, additional information may be collected on recreational resources, wildlife resources, and so forth. Further examples of more recent other elements are information related to biodiversity, either its indicators or surrogates, like quantity and quality of decaying wood, or direct components, like abundance and distribution (diversity) of vegetation species, as well as carbon pools in soil, trees, and coarse woody debris, together with carbon sinks and sources. The need for diverse information has stimulated the development of integrated or multiresource inventories. The forest inventory information is collected in the field and through remote sensing.

The number of variables measured in the field in the current inventories is usually high, typically varying from 100 to up to 400. The great challenge is to develop inventory methods which respond to diverse information needs and still are simpler, cheaper, and yet more accurate in taking measurements and deriving population estimates than the old ones.

The planning of sampling design data collection and statistical inference is a highly statistical problem whose solution needs advanced knowledge in statistical sampling design, current forest inventory systems, forest mensuration, remote sensing, and computer science as related to forest inventory.

This article discusses basic principles and concepts in forest inventory, sampling methods, and statistical inference, including field measurement-based inventory and multisource inventory.

Statistically Designed Forest Inventories

The history of statistically designed forest inventories dates back to the end of the nineteenth century and the beginning of the twentieth century, when county-level and municipality-level forest resource inventories were carried out in Norway, Sweden, Finland, and the UK. The early Nordic forest inventories inspired some of the pioneering work on the statistical accuracy assessment in the context of systematic sampling, particularly error estimation of linewise survey sampling. Statistical knowledge has thus been utilized and also promoted in Nordic forestry literature between 1900 and 1930. This knowledge became common in other parts of the world between 1930 and 1950.

Statistical Problems in Forest Inventory

The total counting of quantities of forests is not possible due to large areas and large numbers of trees (often tens or hundreds of billions within one country). Therefore, either rapid visual assessment by units, e.g., by forest stands, must be applied, or total counting in small subareas. Visual assessment is often the method in operative and management inventories. Estimates may be biased and statistical analysis of reliability is difficult. National and regional inventories are based on sampling with accurate measurements, and error components are known or estimated, in which case statistical error estimation is possible.

Forest inventory is a good and far from trivial application for statistical sampling methods. Difficulties arise from the large number of parameters to be estimated and the dependencies between different variables, even in different scales. Nearby trees are more similar than those farther apart from each other. Large-scale trends like changes in forest parameters are common. Some of the classical statistical questions are:

- What kind of sampling design is 'optimal'? Simple-minded optimization approaches are not possible in forest inventories, because different variables have different covariance structures and presume different sampling designs. A compromise must often be searched for.
- What type of estimators should be used?
- How does one avoid bias?
- How does one assess the reliability of the estimates?

In present inventories, the field measurements are sometimes combined with satellite images and other georeferenced data into a multisource inventory. It produces both statistics and digital thematic maps for computation units and enables accurate small area estimation and wall-to-wall mapping.

Planning of Sampling Design

The inventory design usually involves designing the layout of the field sample plots, choice and decisions concerning the proportion of temporary and permanent field plots, statistical inference method, as well as the possible role of remote sensing material and technique. The principles and factors affecting field sampling design are discussed in this article.

Examples of the factors affecting sampling design are the purpose of the inventory: which parameters are of interest, the accuracy requirement for different parameter estimates, topographic, economic and transportations conditions, and the spatial correlation of the variables of interest. The design-planning procedure is also affected by existing information on the forest area.

Examples of possible field sampling designs are: (1) simple random sampling; (2) systematic sampling;

(3) stratified random and systematic sampling; (4) multistage sampling; and (5) multiphase sampling. It can be shown that systematic sampling is always more efficient than random sampling if the variables of interest are positively spatially correlated.

Stratification is usually an efficient tool in sample surveys to reduce the variances of the estimates and to increase the efficiency of the survey. In forest inventories, stratification can be done on the basis of aerial photographs, satellite images, or on earlier information. In multiresource inventories, it is a problem to find a stratification which is efficient for most of the variables. Another problem is that the boundaries of strata may change over time. Poststratification is an estimation procedure which avoids the problems related to prestratification. Sample units are drawn independently of the stratification system, stratification is done after selecting the sample, and stratified sampling formulae are applied to the unstratified sample.

A further problem related to prestratification, particularly earlier when photointerpretation was used, was that it could be expensive to do for a large area. Digital analysis of satellite images currently reduces this problem. The advantages of stratification can be preserved but the costs of stratification were decreased using a double sampling for stratification design. The first phase is usually a high number of plots with low intensity of measurements and the second phase is a low number of plots with a high intensity of accurate measurements.

Stratified Random and Stratified Systematic Sample

In stratified systematic sampling, a population of N units is divided into subpopulations of known size, $N_1, N_2 \cdots N_H$ units, respectively, and the sample is selected in each population. These populations are not overlapping, and together comprise the whole population, so that:

$$N_1 + N_2 +, \ldots, + N_H = N$$

If sample units are allocated wisely among the strata, the estimates of the population are more precise than those with the same size of sample and without stratification. The following advantages for stratified sampling in forest inventories can be achieved:

1. Separate estimates of the means and variances can be made for each forest subdivision.
2. Sampling problems may differ markedly in different parts of the population.
3. Administrative convenience may dictate the use of stratification.
4. For a given sampling intensity, stratification often yields more precise estimates of the forest parameters than does a simple random sample of the same size. This will be achieved if the established strata result in a greater homogeneity of sampling units within a stratum than for the population as a whole.

The disadvantages are that the size of each stratum must be known or at least a reasonable estimate must be available, and sampling units must be taken in each stratum if an estimate for that stratum is needed. In forest inventories, stratification is often based on the percentage of forest area, mean volume, topographical features, or site classes. Theoretically, the stratification should be based on the values of the variables of interest. However, there are numerous variables in a normal forest inventory. In practical inventories, aerial photographs and/or satellite images are employed for stratification.

The disadvantage that the sizes must be known can be overcome by means of poststratification, i.e., stratification after selecting the sample. This procedure also has the advantage that the stratification can be done separately for different variables.

Methods to allocate units to strata are found in the sampling literature. The sample sizes can be proportional to population sizes, e.g., forest areas, or they can be optimized taking into account within-strata variances and sampling costs.

Multistage sampling is a design where the ultimate sampling units are selected in stages and samples at each stage are taken from the clusters of sampling units of the previous stage. The principal advantage is to concentrate measurement work close to the locations of the chosen primary sampling units rather than spreading it over the entire forest area.

Many sampling techniques require or gain from advance covariate information either in the design phase (stratification, PPS (probability proportional to size) sampling) or in the estimation phase (regression, ratio estimation). If this information is not available, it can be collected with first-phase sample collecting data on a covariate which is easier and cheaper to measure than the variable of interest itself. Multiphase sampling is primarily used to reduce sampling by collecting a relatively large amount of data of covariates that are easier and cheaper to measure than the variable of interest. Special cases are two-phase sampling or double sampling and double sampling for stratification, if the first-phase sample is used to estimate the sizes of the strata.

For practical reasons, e.g., for reducing the moving time of field crews, and also for increasing cost-efficiency, the sampling units are organized to clusters or line strips. However, line strips are usually less efficient than clusters of plots due to spatial correlation. In practice, there are two different alternatives: systematic clusterwise sampling and stratified systematic clusterwise sampling. In the systematic clusterwise sampling, the clusters are spaced at uniform intervals throughout the population. Rectangular spacing or square grids are often applied in practical inventories.

The relevant questions in planning are: (1) what are the spacing of the clusters? (2) what is the shape of the cluster? (3) what is the number of plots per cluster? (4) what is the ratio of remeasured (permanent) plots and only once-measured (temporary) plots? and (5) what is the size and shape of the field plot? To answer these questions, preliminary information about the spatial distribution of the variables of interest is needed. Correlation as a function of distance between field plots and semivariograms can be used to compare the efficiencies of optional sampling designs. An effective way to compare sampling designs is sampling simulation if a model of forest area is available. This can be obtained from a previous inventory or from satellite image-based estimation of variables of interest. An example of the standard errors of optional sampling designs for mean volume of growing stock is shown in **Figure 1**. The land area is 6.47 million hectares, forest land area 4.19 million hectares, and mean volume on forest land 52.7 $m^3 ha^{-1}$. The test site is in North Finland.

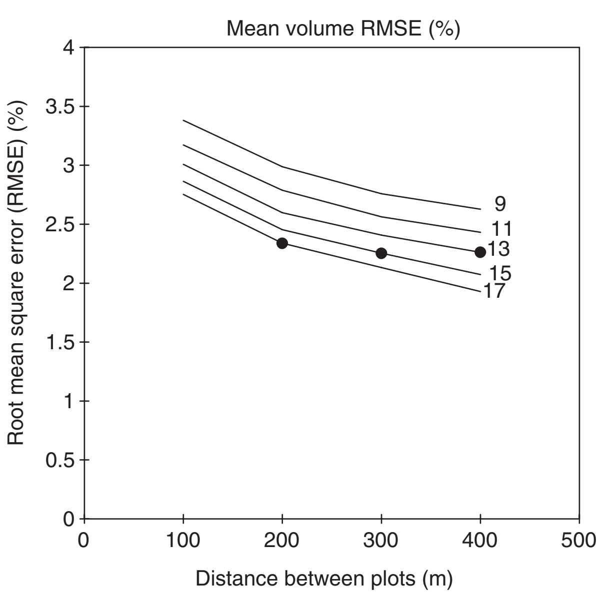

Figure 1 Standard errors based on sampling simulations with different distances between field plots and with number of plots per clusters between 9 and 17. The distance between clusters is 10 km.

One selection concerning the size and the shape of field plot is between a fixed-area sample plot and a sample plot with a varying size for different size of trees. Circular plots are often used in forest inventories. The shape and size problem can be solved using sampling simulation and possible earlier information of the forest area. An example of field sampling design with sample plots is shown in **Figure 2**.

Measurements

The estimates of interest in forest inventories can be grouped into area, volume, and increment estimates. Today, variables describing diversity of ground vegetation as well as carbon pools, sources, and sinks are measured. The measured field plots are usually small for assessing the values of area-based variables, e.g., mean age of trees, or needed silvicultural regimes, so these variables are assessed from a homogeneous forest area intersecting the field plot. This homogeneous forest area is called stand and the variables are stand variables. Examples of stand characteristics are land use, site quality and fertility, and mean characteristics of the growing stock, like tree species composition, number of stems, mean diameter, mean height and mean age of trees, basal area of trees, as well as accomplished and proposed silvicultural, cutting, and drainage measures.

Tree stem volumes and increments by tree species are typical examples of variables whose estimates are based on measurements on field sample plots. Direct measurement of these quantities is, however, not possible. Relationships between direct measurable variables (tree diameter, height) and desired variables (volumes) have to be derived. Measurements are usually done at different intensity levels. Few variables are measured from trees called tally trees, and more variables are taken from a subsample of tally trees, called sample trees. Sampling ratio and variables are selected in such a way that the inventory is as efficient as possible. Tree species and diameter are examples of tally tree variables while height and height increment and diameter increment are examples of sample tree variables.

Tree Level Volume and Increment Estimation

Tree stem volume is still one of the key variables in forest inventories. It is usually measured over bark and is defined as above-stump volume and can be expressed as an integral $v = \int_a^b A(X)\mathrm{d}X$ where *A(X)* is a cross-sectional area of the stem at height X. The cross-section is usually assumed to be a circle when *A(X)* can expressed as a function of

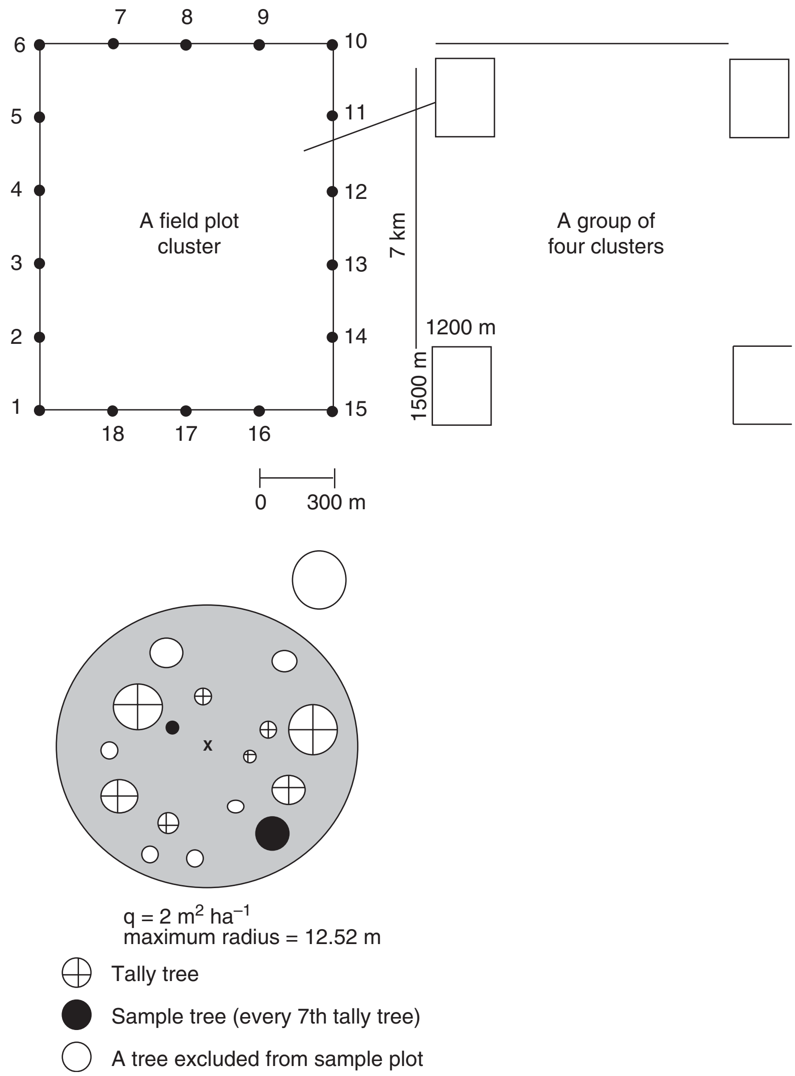

Figure 2 Sample plot and sampling design of the ninth National Forest Inventory (NFI9) in Central Finland. Three of four clusters consist of temporary plots (18 plots) and one is established permanently (14 plots; the plots 11–14 are not measured).

tree diameter at height X. This function is often called taper curve. Sample tree volumes are often predicted as a function of variables which can be measured in the field, e.g., current volume over bark $v_{ob,0} = f$ (tree species, d_{h_1}, d_{h_2}, h) where d_{h_i} is the diameter of the stem at the height of h_i and h is the height of the tree. Taper curve models can be used to predict the volumes of logs. The volumes for tally trees are estimated by strata using the volumes of sample trees, measured tally tree variables, and either parametric or nonparametric regression analysis.

Tree Growth

Tree growth consists of elongation and thickening of roots, stem, and branches and causes changes in tree stem form and dimensions. Tree stem volume increment can be predicted as a function of measurements, e.g., as a function of height increment and diameter increment at certain heights. The increase in a tree dimension is qualified by the period of time during which the increment has occurred. Current annual increment is the difference between dimensions at the beginning and end of the current year. Periodic annual increment is the average increment for a periodic of years. Increment can be predicted directly from the measurements or indirectly as a difference of the current volume and the volume at the beginning of the growth period, e.g., as a function $v_{ob,-5} = g$ (tree sp, $v_{ob,0}, g_{ub,0}, g_{ub,-5}, h$) where $g_{ub,t}$ = basal area under bark at time point t. The annual increment for sample trees is $i_v = (v_{ob,0} - v_{ob,-5})/5$ if the period is 5 years.

Estimation and Error Estimation from Field Data

The estimates in forest inventory can be divided into area and volume estimates as well as mean values and totals, for example, area of forest of a certain age class and mean volume of a pine-dominated forest. Both the sampling design and the parameter estimation can be done in different ways. One basic division is into design-based inference and model-based inference. Stratification can be done by the design and by a model. As noted earlier, stratification can be done either before or after sampling. The interesting parameters in forest inventory are often of the form:

$$M = \frac{Y}{X} \tag{1}$$

where Y and X are expectations of two random variables x and y, e.g., y is an indicator of land class or the volume of a tree species and x is the indicator of a stratum of interest, e.g., forestry land. Let $x_{id'}$ and y_{id} be their observed values on sample plot i in the domains of interests d' and d. The ratio estimator of M is

$$\hat{m} = \frac{\sum_{i=1}^{n} y_{id}}{\sum_{i=1}^{n} x_{id'}} = \frac{\overline{y_d}}{\bar{x}_{d'}} \tag{2}$$

where n is the number of sample plots in the inventory area.

When stratification is applied, the ratio estimator is:

$$\hat{m}_{st} = \frac{\hat{Y}_d}{\hat{X}_{d'}} = \frac{\sum_{h}^{H} W_h \overline{y}_{hd}}{\sum_{h}^{H} W_h \overline{x}_{hd'}} \tag{3}$$

where W_h are the stratum weights, $\overline{y}_{hd}$ and $\overline{x}_{hd'}$ stratum sample means in the stratum h and domains d and d'.

When double sampling for stratification is applied, i.e., stratum weights are not known, the estimator is of the form:

$$\hat{m}_{st} = \frac{\hat{Y}_d}{\hat{X}_{d'}} = \frac{\sum_{h}^{H} \frac{n'_h}{n'} \overline{y}_{hd}}{\sum_{h}^{H} \frac{n'_h}{n'} \overline{x}_{hd'}} \tag{4}$$

where n' and n'_h are the sample size and sample size in the stratum h in domain d'. The variance estimator of equation (4) is:

$$v(\hat{m}_{st'}) = \frac{1}{\hat{X}_{d'}^2}[v(\hat{Y}_d) + \hat{R}^2 v(\hat{X}_{d'}) - 2\hat{R}\,\mathrm{cov}(\hat{Y}_d, \hat{X}_{d'})] \tag{5}$$

where $v(\hat{Y}_d)$ and $v(\hat{X}_d)$ are the variance estimators for (double) sampling for stratification.

The normal variance estimator is not necessarily a good measure for the reliability of estimates in forestry applications due to the spatial autocorrelation and possible trend-like changes of the target variables. Matérn suggested the quantity $E(m - M)^2$, the error variance, as a measure of reliability of the estimator and also proposed an estimator for the error variance. He considered the groups of field plot clusters within possible strata and deviances of the cluster means from the stratum mean. The quadratic forms of the deviances, computed from groups of clusters, often from groups of four clusters, can be used as terms of the error variance estimator. The method can be applied to stratified sampling as well. The standard error estimators for the whole area of interest can be obtained by combining the stratum-specific estimators with the usual formula for stratified sampling.

Multisource Estimation

Aerial Photographs

Aerial photographs have been used in large-area forest inventories since the late 1920s in Canada, the 1930s in the USA, and the 1940s in Europe, the tropics, and Russia. Mapping, land cover classification and measurements, e.g., tree dimensions, are typical applications. In large-area inventories, a natural statistical framework for the use of the images is double sampling for stratification. Photo interpretation or estimation represents phase 1 and field inventory phase 2. Areas of strata are estimated using aerial photographs. A kind of application of double sampling is also the grouping method applied in the Finnish national forest inventory (NFI) in North Finland. A great benefit of the procedure is that each photo plot receives a formally complete data vector. Large-scale (aerial photographs) (1:5000 to 1:10 000) can be used to measure tree dimensions, such as height of trees and canopy dimensions.

Digital analysis of aerial photographs is still problematic due to varying illumination conditions and viewing angle of targets within one image. The trend in both stratification and estimation is today towards the use of digital satellite images and digital analysis.

Satellite Images

It was long considered that the resolution of natural resource satellites like Landsat TM, or ETM+, Spot XS, is not high enough for forest inventory purposes. The often-applied classification approach was not sufficient for forest inventory purposes, except for stratification. Standard errors at picture element (pixel) level are still high with all methods and for most forest variables. However, the developments during the last 10–15 years have shown that satellite images have a role in forest inventories, in spite of their limitations. The new very high resolution image may in future have a similar role as high-altitude aerial photographs.

There are already operational and some semi-operational applications based on co-use of field measurements and satellite images, sometimes supplemented by digital maps or land cover data.

The goal of using satellite images in national forest inventories may either be to compute estimates for smaller areas than is possible using field measurements only, e.g., for areas typically of a size of some 10 000 ha (the Finnish NFI) or to decrease the standard errors at medium-level areas, e.g., some 1–2 million hectares (the USA NFI). These goals and methods are not independent. However, the previous one is closer to synthetic small-area estimation while the latter one involves poststratification, or double sampling for stratification. The possibility of producing wall-to-wall digital forest maps in both systems is an extra benefit of the use of satellite images (**Figure 3**). The estimation method in both applications is what is called k-nearest neighbor (k-NN) estimation. The basic idea is as follows.

The procedure utilizes a distance metric, $d_{pi,p}$, which is computed in the feature space from pixel p to each pixel p_i, whose ground truth is known (to pixel with sample plot i). Data from the k plots, $i_1(p) \ldots i_k(p)$ with the shortest distances are employed

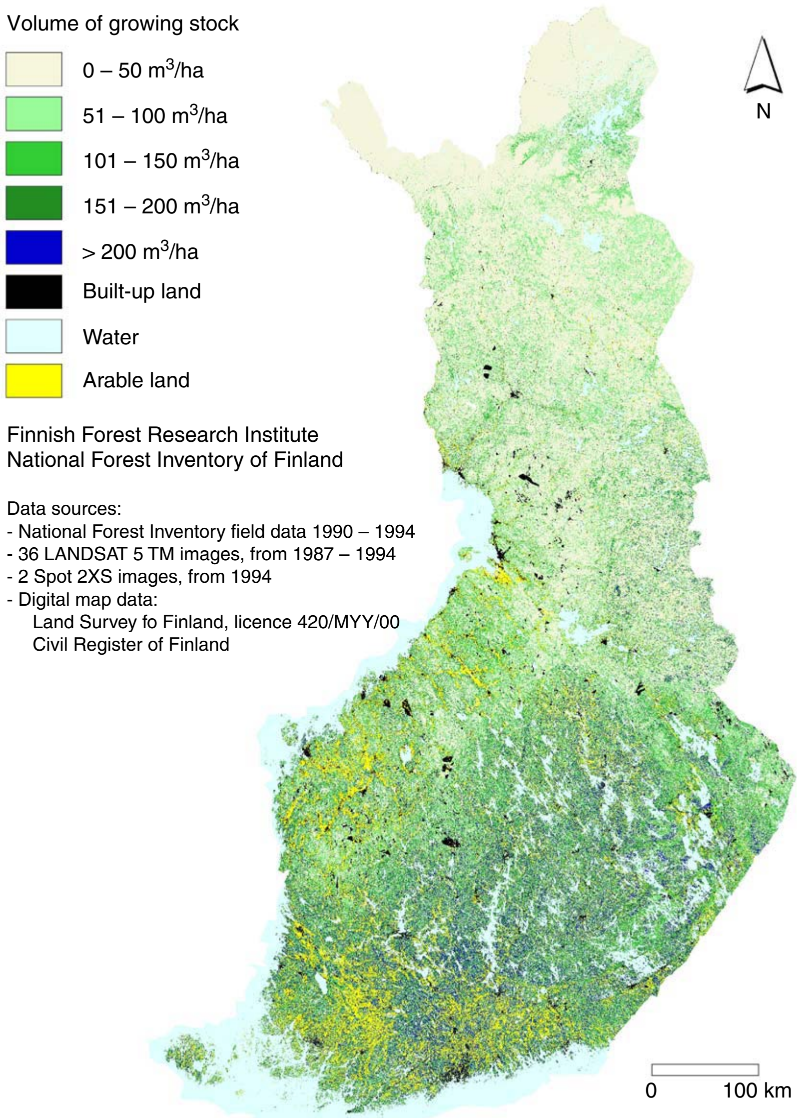

Figure 3 Mean volume of growing stock ($m^3 ha^{-1}$) based on multisource national forest inventory. Pixel size is 25×25 m and volumes are given with a resolution of $1 m^3 ha^{-1}$.

in the analysis of pixel p. A maximum distance in the geographical space (usually 50–100 km in the horizontal direction and some hundreds of meters in the vertical direction) is set from the pixel p to the sample plots in order to avoid utilizing sample plots from very different vegetation zones.

The weight of the ground data vector of plot i to pixel p is then defined by:

$$w_{i,p} = \frac{1}{d^2_{p_i,p}} \sum_{j \in \{i_1(p),\ldots,i_k(p)\}} \frac{1}{d^2_{p_j,p}} \quad \text{if } i \in \{i_1(p), \ldots, i_k(p)\}$$
$$= 0, \ \text{otherwise.} \qquad (6)$$

Sums of weights $w_{i,p}$ are calculated by computation units (for example, by forest counties) in the image analysis process. The weight of plot i to computation unit u is then:

$$c_{i,u} = \sum_{p \in u} w_{i,p}. \qquad (7)$$

This quantity can be interpreted as the area represented by plot i in unit u, or stratum weights when each stratum consists of one plot only. The estimation returns to the estimation using field data only.

The accuracy of the estimates can be improved if land use or land cover classes can be distinguished by means of digital maps, as in the Finnish NFI.

Information from field plots and maps can be employed to remove the effect of map errors from the estimates.

Error Assessment in Multisource Inventory

Estimation of sampling error in forest inventory presents some difficulties, even if only field sample plots are applied. The reasons are systematic sampling, spatial correlation, and trend-like changes in the target variables. The assessment of reliability of the estimates is even more difficult when a multisource technique is applied.

If the k-NN method is used for stratification, variances of stratified sampling can be used as error estimates. In the case of synthetic estimation, the analytic error estimation is yet to be found.

For the k-NN method, the RMSE of the pixel level estimates can be statistically assessed by cross-validation. However, the error in the estimate of a forest parameter in one pixel is highly dependent on the true value there, and thereby the errors are spatially correlated. The error structure is made even more complex by the spatial dependencies in the image itself. The inevitable inaccuracies in locating the field plots on the image must clearly have a stronger effect on the pixel level estimates than those for larger areas. Developing an operationally usable statistical error assessment technique is a highly challenging task, and a fully satisfactory solution is yet to be found.

Future Directions

Both increasing timber production demands and ecological and environmental needs for forest information necessitate the further development of the inventory methods. To achieve these requirements, it is necessary to have up-to-date georeferenced forestry data systems with precise knowledge about log specifications and the status of the forest ecosystem.

Technical progress in satellite and airborne imaging will bring radiometrically and spatially improved sensors and imaging systems. Examples are very-high-resolution optical area images (Ikonos, QuickBird), imaging spectrometers and laser instruments and active microwave instruments. Microwaves penetrate through clouds without changing and imaging is, in principle, possible under any condition. Research has shown, however, that the backscattering depends very much on the canopy and soil moisture conditions, so interferometry and multitemporal images are needed.

Forest inventories have traditionally produced information about forest biodiversity. The extent and quality of habitats which maintain valuable flora and fauna, and volume and quality of dead decaying wood are examples of new characteristics describing forest biodiversity. The output wall-to-wall maps of multisource inventories can be employed to assess the landscape level biodiversity and the effect of the structure of the growing stock on the abundance of species.

The measurement technique is developing as well. Digital instruments are already employed in many large-area inventories. Digital imaging of tree stems and canopies provides new methods to estimate the volumes of stem parts and biomass of trees.

The future global forest inventories may be based on the co-use of digital field measurements, airborne instruments, such as imaging spectrometers, laser instruments, and scatterometers as well as satellite images of optical and microwave area. Old inventory data, together with mathematical forest development models and new data sets, will be applied in the estimation. The roles of different input information sources vary depending on the application and information needs. Sampling at different resolutions will be applied. Results will consist of estimates of parameters with reliability assessments and digital maps describing forest resources and the forest ecosystems.

See also: **Inventory**: Modeling. **Mensuration**: Forest Measurements; Timber and Tree Measurements; Yield Tables, Forecasting, Modeling and Simulation. **Resource Assessment**: Regional and Global Forest Resource Assessments.

Further Reading

Avery TE and Burkhart HE (1983) *Forest Measurements*. New York: McGraw-Hill.

Cochran WG (1977) *Sampling Techinques*, 3rd edn. New York: Wiley.

Cunia T (1978) On the objectives and methodology of national forest inventories. In: *Forest Resource Inventory*, pp. xi–xxxi. Joint Meeting of IUFRO Groups S4.02 and S4.04. 18–26 June 1978. Bucharest: Institutul de Cerctari si Amenageri Silvice.

FAO (2001) *Global Forest Resources Assessment 2000. Main Report*. FAO forestry paper 140. Rome: FAO.

Husch B, Miller CI, and Beers TW (1982) *Forest Mensuration*. New York: John Wiley.

Ilvessalo Y (1927) The forests of Suomi Finland. Results of the general survey of the forests of the country carried out during the years 1921–1924. [In Finnish with English summary.]. *Communicationes ex Instituto Quaestionum Forestalium Finlandie* 11: 321–395.

Loetsch F and Haller KE (1973) *Forest Inventory*, vol. I. Munich: BLV Verlagsgesellschaft.

Loetsch F, Zöhrer F, and Haller KE (1973) *Forest Inventory*, vol. II. Munich: BLV Verlagsgesellschaft.

Matérn B (1960) Spatial variation. Meddelanden från statens skogsforskningsinstitut. 49(5). Stockholm, Sweden. Also appeared as Lecture Notes in Statistics 36 (1986). New York: Springer-Verlag.

McRoberts RE, Nelson MD, and Wendt DG (2002) Stratified estimation of forest area using satellite imagery, inventory data, and the k-nearest neighbors technique. *Remote Sensing of Environment* 82: 457–468.

Poso S (1972) A method of combining photo and field samples in forest inventory. *Communicationes Instituti Forestalis Fenniae* 76(1): 1–133.

Ranneby B, Cruse Th, Hägglund B, Jonasson H, and Swärd J (1987) Designing a new national forest survey for Sweden. *Studia Forestalia Suecica* 177: 29.

Särndal CE, Swenson B, and Wreteman J (1992) *Model Assisted Survey Sampling*. New York: Springer-Verlag.

Schreuder HT, Gregoire TG, and Wood GB (1993) *Sampling Methods for Multiresource Forest Inventory*. New York: John Wiley.

Study on European Forestry Information and Communication Systems (1997) *Reports on Forestry Inventory and Survey Systems*, vols 1–2. Brussels, Belgium: European Commission.

Tomppo E (1996) *Multi-source National Forest Inventory of Finland. New Thrusts in Forest Inventory*. Proceedings of the Subject Group S4.02-00 'Forest Resource Inventory and Monitoring' and Subject Group S4.12-00 'Remote Sensing Technology,' vol. 1. IUFRO XX World Congress 6–12 August 1995, Tampere, Finland. EFI Proceedings no. 7. Tampere, Finland: European Forest Institute.

Regional and Global Forest Resource Assessments

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Introduction

Forests and other wooded lands have been recognized and highly valued as important natural resource for centuries. The list of benefits that people gain from forests is very impressive. Forest resources play a vital role not only for the economic, social, and cultural well-being of local and regional communities, but also for the maintenance of life on earth as a whole. The majority of forest functions, both wood and non-wood goods and services, are well known. For some forest functions and services, their features and potential still need additional research, but all forest resources need a comprehensive and reliable assessment, as a basis for their proper utilization and management in an efficient and sustainable manner.

The Food and Agriculture Organization of the United Nations (FAO) and UN Economic Commission for Europe (UNECE) have implemented assessments of forest resources at the regional and global levels for more than half a century. The assessments are carried out in collaboration with countries and partner organizations. The UNECE, one of the five UN regional commissions, contributes to the forest resources assessments from the regional perspective. Other partners, notably the United Nations Environment Programme (UNEP), carry out multicountry surveys reflecting the global or regional situation regarding different aspects of forest resources.

The periodic international Forest Resources Assessments at the regional, subregional, and global levels are an important source of knowledge about forests and other wooded lands. Traditionally, the Forest Resources Assessments focus on a number of key parameters/variables (areas, growing stock, increment, species composition, ownership categories), their status and changes over time. The list of parameters to measure is evolving from assessment to assessment under the pressure of demands for new and more detailed and accurate information. The FAO and UNECE/FAO Forest Resources Assessments have been carried out at 5–10-year intervals and provided a unique source of data for many forest- and