CALCULATION SYSTEM FOR LARGE-SCALE FOREST INVENTORY

Kari T. Korhonen

Metsäntutkimuslaitoksen tiedonantoja 505

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Summary: This paper describes a calculation system for large-scale forest inventory. National Forest Inventory data from the Forestry Board District of Kainuu are used for demonstrating the calculation system. Mixed estimation is used for estimating localized volumes functions from the sample tree data measured in the inventory and data measured in a previous inventory. Ordinary least squares -technique is used for estimating growth models and volume functions by timber assortments. Estimated models and some basic statistics calculated for the test area are presented.

Keywords: forest inventory, mixed estimation, models, volume, growth

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Joensuu 1.6.1994 Kari T. Korhonen

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Concepts and Notation

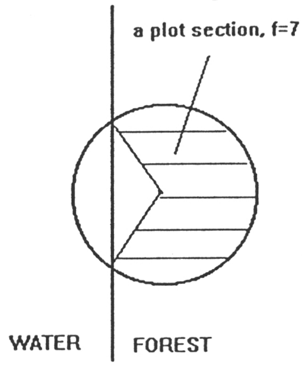
The following concepts related to the measurements of the field data are used in this paper.

sample point = a point where a relascope plot is measured

relascope plot = a set of concentric circles with each circle having a fixed radius for each diameter (the radius is a function of the cross sectional area of the tree)

restricted relascope plot = a relascope plot having a maximum radius; trees with distance from the sample point greater than the maximum radius are not tallied

plot section = section of a plot, when the plot is near a land-class boundary



plot factor = relative size of a plot; when a plot is located near a land-class boundary and the center point of the plot is on forestry land, the plot factor indicates the proportion of the whole plot circle made by the plot section on forestry land

plot stand = stand containing trees tallied on a relascope plot, usually a plot contains trees from only one stand; delineation of stands is based on the characteristics of the site and the growing stock

tally tree = a tree belonging to the (restricted) relascope plot

sample tree = a tally tree for which more detailed measurements are taken timber tree = tally tree containing high enough timber quality for at least one saw log

non-timber tree = tally tree whose dimensions and/or quality are not enough for any saw logs

The following notations for the most common tree and stand variables are used in this paper.

d = diameter at breast height (1.3 meters from the ground), cm

h = height of a tree, m

d_6 = upper diameter of a tree measured at a height of 6 m from the ground, cm

v = stem volume of a tree from stump height to the top of the tree, dm^3

v_t = volume of the timber part of the stem, dm^3

v_w = volume of the cull part of the stem, dm^3

g = cross-sectional area of a stem at breast height, cm^2

i_d = diameter increment of the past five-year period at breast height, cm

i_h = height increment of the past five-year period, dm

b = thickness of bark (sum of measurements from two sides of the stem), mm

d_i = diameter inside the bark, cm

g_i = cross-sectional area inside the bark at breast height, cm^2

$r = v/g_i$

d_5 = diameter at the beginning of the past 5-year period, cm

h_5 = height at the beginning of the past 5-year period, m

t = age of a tree at breast height, a

g_{i5} = cross-sectional area inside the bark at breast height at the beginning of the past 5-year period, cm^2

v_5 = volume of a tree at the beginning of the past 5-year period [dm^3]

Vu = 'unit volume' of a tree (Vu=v/g)

SVu = 'seed volume' of a tree, (SVu=v_5/g)

V = volume sum of a plot (section), sum of the volumes of measured trees multiplied by the number of stems, m^3/ha

F = plot factor, relative size of a plot or of a plot section

G = basal area of the growing stock, m^2/ha

D = mean diameter (weighed with basal area) of the growing stock, cm

T = mean age of the dominant trees, a

S1 = 1, if the site class of the plot stand is 1 (i.e. IA or IB
according to the Finnish tax-class system)
0, otherwise

S2 = 1, if the site class of the plot stand is 2 (i.e. II
according to the Finnish tax-class system)
0, otherwise

S3 = 1, if the site class of the plot stand is 3 (i.e. III
according to the Finnish tax-class system)
0, otherwise

SOIL = 1, if the soil type is mineral soil
0, otherwise

DD = effective temperature sum at the location of a plot = sum of daily mean temperatures exceeding 5 degrees Celsius, ° Celsius

DIST = distance from the coast (of the Gulf of Bothnia or the Gulf of Finland), km

RDIST = 0, if DIST > 20
1/DIST - 0.05, otherwise

Y = y-coordinate of the plot (distance from the Equator), km

YC = (Y-6620)/1000

X = x-coordinate of the plot (distance from the meridian of Greenwich, England), km

XC = (X-60)/1000

q = basal area factor (BAF)

ln(X) is the natural logarithm of variable X

1. BACKGROUND

In large-scale forest inventories sampling methods are used to obtain a representive sample of the population. In many cases it is not possible or rational to measure directly those variables that we are interested in. Therefore, mathematical methods (also methods other than simple summation) are needed to derive the statistics of final interest from the characteristics measured for the sample.

A complete calculation system of inventory results should include following components:

1. checking of field data,
2. derivation of volumes, volume growth etc. for sample trees using existing models and measured data,
3. generalization of volumes and other characteristics for tally trees,
4. summation of statistics for any chosen calculation stratum, and
5. estimation of reliability of the results.

The aim of this study was to develop a system of calculation for the National Forest Inventory of Finland (NFI). The system should be based on tested and documented methods and should cover estimation of areas of different strata (e.g. forest types), mean volume, growth and percentages of timber assortments. Estimations of future growth and cutting possibilities are, however, excluded from the system. Nor are procedures for detecting errors in the field data nor estimation of sampling error within the scope of this study.

The calculation system is tested using Kainuu district as a study area.

2. MATERIAL AND METHODS

2.1 Study material

Data from the 7th National Forest Inventory of Finland (NFI7) for the whole country and data from the 8th National Forest Inventory of Finland (NFI8) for Kainuu district (see Fig. 1) were used in this study. The NFI7 was carried out during 1977-1984 (Kuusela & Salminen 1991). The NFI8 data for Kainuu district were measured in 1992.

In both inventories the sampling method was systematic cluster sampling. In the NFI7 the distance between clusters was 8 km and each cluster consisted of 21 relascope plots. In the NFI8 in the Kainuu district the distance between clusters was 7 km and each cluster consisted of 15 restricted relascope plots.

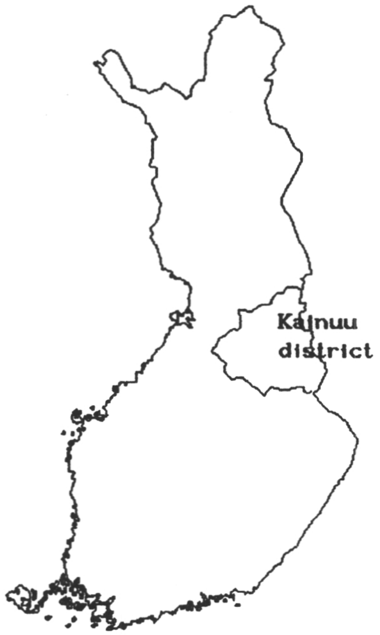


Figure 1. Location of Kainuu district.

In both inventories, several variables describing the site and growing stock of the plot stand(s) were recorded. Tallied trees were selected with a relascope. In the NFI7 a relascope with a basal area factor of 2 was used. In the NFI8 in Kainuu district a restricted relascope plot with a basal area factor of 1.5 and a maximum radius of 12.45 m was used. In both sets of data the following variables were recorded for every tallied tree:

- tree species
- diameter
- quality class describing the quality of the stem, later called 'tally tree quality class'
- crown class.

In the NFI7 data, the living trees were divided into 3 quality classes: non-timber trees (based on the dimensions of the stem), non-timber trees (based on defects on the stem), and timber trees. In the NFI8 data a more detailed classification was used to describe, e.g. whether a timber tree is of good or poor quality.

In the NFI7, tally trees measured at four plots in every cluster were used as sample trees. In the NFI8 every 7^{th} tallied tree was measured as a sample tree. In both sets of data the following variables were registered for sample trees:

- height
- age
- length and location of different timber assortments (=saw log quality classes A, B, and C; pulp wood; cull)
- diameter increment for the past 5-year period
- height increment for the past 5-year period (only for conifers).

In addition to above mentioned variables, diameter at six meters height and thickness of bark at breast height were registered for all sample trees in the NFI7 data and for a sub-sample of sample trees in the NFI8 data.

In the NFI8 data a variable called 'sample tree quality class' was also recorded. This variable describes the cruisers opinion of the quality of the stem after measurement of the sample tree. The 'tally tree quality class' describes the cruiser's opinion about the quality before the sample tree was measured. The cruiser may change his opinion about the quality during detailed examination of the stem when measuring the characteristics of the sample tree.

2.2 Methods

The first phase in the calculations is to derive volume, growth and percentages of timber assortments for every sample tree measured. The volumes of the trees were calculated using volume functions of Laasasenaho (1982). Volumes of timber assortments were calculated using the taper curve models of Laasasenaho (1982) as a function of d, d_6, and h. Volume increment of the sample trees was estimated according to the methods described by Salminen (1978) and Kujala (1980).

Regression analysis (Ordinary Least Squares, OLS) and mixed estimation were used to estimate the volume and increment of tally trees. Mixed estimation is widely used in problems requiring combination of two or more data sets (Teräsvirta 1981). Korhonen (1992, 1993) has shown that mixed estimation is efficient for combining sample tree data from two inventories.

SAS statistical software was used for studying the relationships between different measured variables in order to determine the correct form of the necessary models (SAS Institute Inc. 1989). The parameters of the models were estimated with Fortran-programs made by the author. IMSL-routines were used for matrix operations (such as inversion) in these programs (IMSL library... 1982). The reason for selecting Fortran-programs instead of available statistical software was that Fortran-programs makes it possible to simulate sampling and thus test the methods used in the calculation system. Fortran-programs were also used to derive the volumes of different timber assortments for sample trees measured.

Volume and growth of tally trees were estimated with Fortran-programs developed by the author. The treewise characteristics were summed up into statistics for the whole calculation area with SAS statistical software.

3. DESCRIPTION OF THE SYSTEM

3.1 Processing sample tree data

3.1.1 Estimation of volumes

In the NFI8 data, d and h were measured for every sample tree. Upper diameter, d_6, however, was measured only for a sub-sample of the sample trees. The first phase in the calculation of volumes was to construct models for estimating the upper diameter of all sample trees (higher than 8 meters). Function (1) was applied as the model (Korhonen 1992) but was used in its full form only for pine and spruce. For other species, only variables d^2, h^2, d/t, and $\ln(\hat{d}_{6L})$ were significant regressors; the rest of the variables were excluded from the model.

$$\ln(d_6) = a_0 + a_1*d^2 + a_3*h^2 + a_4*d/t + a_5*\ln(\hat{d}_{6L}) +$$

$$a_6*\ln(G) + a_7*YC + a_8*YC^2 + a_9*XC + a_{10}*XC^2 +$$

$$+ a_{11}*YC*XC, \qquad (1)$$

where d_6 = diameter measured at 6 meters height,
d = diameter at breast height,
h = height,
t = age of the tree at breast height,
$\hat{d}_{6L}$ = upper diameter estimated using the taper curve model of Laasasenaho (1982) with d and h as independent variables,
G = basal area of the growing stock,
YC = relative y-coordinate of the plot (see 'Concepts and Notation'), and
XC = relative x-coordinate of the plot (see 'Concepts and Notation').

The parameters of the model (1) for each tree species were estimated using mixed estimation. In the first stage of the estimation process, first-level estimates of parameters were obtained using NFI7 data for the whole country. In the second stage, second-level estimates of parameters a_0 - a_6 were obtained using NFI8 data from Kainuu district (Korhonen 1992). Parameters related to the coordinates are not estimeted in the second stage because the data measured in this stage are quite few and geographically not representative.

When all sample trees have measured values for variables d and h and all trees higher than 8 meters have a measured or estimated value for variable d_6, the stem volume (from the estimated stump height to the top of the tree) can be estimated with the functions presented by Laasasenaho (1982).

Estimation of timber assortments is based on the dimensions of the stem (d, d_6, h) and the measured lengths of different quality classes. These measurements were used to divide the stem into saw logs that fulfilled the dimension (top diameter and length) requirements. The stem was divided into saw logs by maximizing the value of the stem with a 'complete enumeration' method. In this method, all possible solutions (=combinations of saw logs of different lengths) are tested and the solution that gives the best value is chosen. This timber ruling was made with a Fortran-program in which the dimension requirements (minimum and maximum lengths and minimum diameters) and relative values of different assortments are optional parameters so that they can easily be changed.

3.1.2 Estimation of volume increment

The sample tree variables that are related to the estimation of growth are diameter and height increment during the past 5-year period and thickness of the bark. The bark is measured only for some of the sample trees. Therefore, a regression model was constructed for estimating the thickness of the bark. Function (2) was found as a suitable model for pine.

$$b = a_0 + a_1*d + a_2*h, \qquad (2)$$

where b = thickness of bark.

For other species a logarithmic model (Function 3) was found to be necessary to solve the problem of heteroscedasticity.

$$\ln(b) = a_0 + a_1*\ln(d) + a_2*\ln(h). \qquad (3)$$

For decidious trees height increment was not measured. Therefore, this variable was estimated using the tables of Ilvessalo (1948, see Kujala 1980), in which height, age, and crown class of the tree are independent variables.

When the bark models are estimated, each sample tree have measured or estimated values for variables related to volume growth: diameter and height increment and thickness of the bark. No characteristics are measured to directly describe the changes in stem form and in thickness of the bark during the past 5-year period. When calculating the volume increment these changes can be taken into account with the method presented by Salminen (1978) and Kujala (1980). In this method it is assumed that the change in v/g_i (ratio of volume and cross sectional area) during the past 5-year period can be estimated with help of a function (v/g_i=f(h)) estimated from the present v, g_i and h of the trees.

To describe the method of Salminen (1978) and Kujala (1980), let us note that:

$$r = v/g_i, \tag{4}$$

r(h) = a function that estimates r as a function of height,

$$Vu = v/g \tag{5}$$

(Vu is the unit volume of a sample tree = volume of the tree divided by its cross sectional area), and

$$SVu = v_5/g \tag{6}$$

(SVu is 'seed volume' of a relascope tree = the volume of the tree 5 years ago divided by its present cross sectional area)

Formula (6) for SVu can be further written as follows:

$$SVu = g_{i5}/g * (v_5/g_{i5})$$

$$\Leftrightarrow$$

$$SVu = g_{i5}/g * (v/g_i - (v/g_i - v_5/g_{i5}))$$

$$\Leftrightarrow$$

$$SVu = g_{i5}/g * v/g_i - g_{i5}/g * (v/g_i - v_5/g_{i5})$$

$$\Leftrightarrow$$

$$SVu = g_{i5}/g * (g/g_i * v/g - (v/g_i - v_5/g_{i5})) \qquad (7)$$

Using notation Vu for v/g, $\hat{f}(h)$ for estimated v/g_i, and $\hat{f}(h_5)$ for estimated v_5/g_{i5}, Function (7) can be written:

$$SVu = g_{i5}/g * (g/g_i * Vu - (\hat{f}(h) - \hat{f}(h_5))). \qquad (8)$$

After the 'seed volume' of a tree is estimated using Function (8) and areas in cross section and heights now and 5 years ago are measured, the volume 5 years ago can be calculated with Formula (9):

$$v_5 = g * SVu \qquad (9)$$

3.2 Estimation of volumes and increment for tally trees

3.2.1 Volume functions

Functions for estimating the volume of the whole stem from stump to the top of the tree were constructed using sample trees measured in the NFI7 and the NFI8. The two data were combined using mixed estimation (Korhonen 1993). At the first stage of the construction of the volume functions, NFI7 data were used for determining the form of the models and for obtaining first-level estimates of the parameters. In a previous study (Korhonen 1993) Function 10 was shown to work well for pine.

$$v / d_2 = a_0 + a_1*d + a_2*d^2 + a_3*RDIST + a_4*\ln(G) + a_5*YC + a_6*YC^2 + a_7*XC + a_8*XC^2 + a_9*YC*XC, \quad (10)$$

where RDIST = relative distance from the sea coast (see 'Concepts and Notation').

Function (10) was also found to be satisfactory for spruce and birches. For other species, the variable RDIST was excluded from the model.

At the second stage in the construction of the volume functions, mixed estimation was used for obtaining second-level estimates of the parameters (Korhonen 1993). Only data from the calculation area (typically one district of the Central Board of Forestry in Finland) were used for the re-estimation. Because the number of sample trees measured was quite high for pine, spruce and birches, models were estimated separately for each site class. Only constant and parameters of variables d, d^2, and ln(G) were estimated at the second stage; for other variables, first-level estimates were used (Korhonen 1993).

Regression models were also constructed for estimating the volumes of different timber assortments: timber and cull. The volume of pulp wood quality was estimated by subtracting the estimated volumes of timber and cull from the estimated stem volume. A function with a form of Equation (11) was found to be suitable.

$$v_t / d^2 = a_0 + a_1*\ln(d) + a_2*DD, \quad (11)$$

where v_t = volume of timber or cull and
DD = effective temperature sum at the location of the plot.

Because the form of the Function (11) for timber assortmentwise volumes differs markedly from the Function (10) for whole-stem volume, it was also necessary to estimate a model of a form similar to Equation (11) for stem volume. Otherwise, all errors due to the form of the functions would have been summed up in the volume estimate for pulp wood. In some cases this could even have led to negative estimates for pulp wood. Final estimates for, e.g. the saw log volume of a tally tree were then obtained with formula (12).

$$\hat{\hat{v}}_t = \hat{v}_t/\hat{v}_2 * \hat{v}_1 , \tag{12}$$

where $\hat{\hat{v}}_t$ = final estimate for v_t,

$\hat{v}_t$ = estimate for v_t obtained with the model for the form of Equation (11)

$\hat{v}_1$ = estimate for v obtained with the model for the form of Equation (10), and

$\hat{v}_2$ = estimate for v obtained with the model for the form of Equation (11).

Because logging rules have changed since the NFI7, it was not possible to use the NFI7 data as prior information. Timber assortmentwise models were estimated using OLS and sample tree data measured from the calculation area.

Naturally, the proportions of timber assortments vary markedly by tree class. Therefore, the sample tree data were grouped by tree classes as follows.

1 = non-timber tree

2 = a good saw log tree

3 = a poor saw log tree.

As mentioned in Section 2.1, in the field measurements two different codes for tree class were recorded for the sample trees. The first of these describes the quality 'at first glance', which refers to the way it is coded for tally trees (later called 'tally tree quality class'). The second one is coded according to more detailed sample tree measurements (later called 'sample tree quality class'). Usually, the codes match, but in some cases the cruiser may change the quality code when taking sample tree measurements. Thus, a sample tree with tally tree class code 'non-timber tree' can include saw log quality, and vice versa.

Only trees with the sample tree quality class code 'good saw log tree' or 'poor saw log tree' were used in estimating the above mentioned regression models for timber assortment volume. At the application stage tally trees were grouped into the respective quality classes according to the tally tree quality class. To avoid possible bias caused by differences in the two quality classifications an adjustment was made as follows. For all sample trees the mean of the measured timber volume and the mean of the estimated timber volume were calculated by tree species. The timber volume estimate of a single tree was then multiplied by the ratio of these two means. A similar adjustment was made for the estimates of cull volume.

3.2.2 Growth models

Model (13) was selected as a basic model for estimating the volume increment of the past 5-year period. For some species not all the variables in the equation were significant regressors. In these cases, only significant variables were used (see Section 4.1).

$$\ln(i_v/d^2) = a_0 + a_1*d + a_2*\ln(d) + a_3*G + a_4*DD + a_5*D/T + a_6*S1 + a_7*S2 + a_8*S3 + a_9*SOIL \quad (13)$$

where S1, S2, S3 are dummy variables for different site classes, and SOIL is a dummy variable to separate mineral soils form peatlands.

When the growth models were estimated, trees growing on poorly productive land were separated from trees growing on forest land for two reasons:

1. the growth of trees growing on poorly productive land is markedly different from the growth of trees on forest land, and
2. most of the variables describing the growing stock are not measured on poorly productive land.

Equation (14) was used as a growth model for trees on poorly productive land.

$$\ln(i_v/d^2) = a_0 + a_1*d + a_2*\ln(d) \quad (14)$$

The natural logarithm of i_v/d^2 is used as an dependent variable in models (13) and (14). In applications, unbiased estimates for i_v/d^2 in the arithmetic scale are needed. The most common way to correct the bias due to the non-linear transformation is to add the term 1/2*MSE to the logarithmic estimate. This correction is based on the assumption that the residuals of the logarithmic model are normally distributed. If this does not hold true, following estimator can be justified according to Snowdon (1991):

$$\hat{y}_i = c*\exp(\hat{\mu}_i), \tag{15}$$

$$\text{where } c = \frac{\Sigma\, y_i}{\Sigma \exp(\hat{\mu}_i)},$$

y_i = measured value for observation i, and

$\hat{\mu}_i$ = estimated logarithmic value for observation i.

Estimator (15) was used in this study to correct the bias due to the non-linear transformation in growth models.

3.3 Generating reports

Using the models described in Section 3.3, the field data are transformed into a file, which is suitable for further processing with SAS statistical package. In this file, each plot stand has one record for characteristics describing the location of the plot and site and the growing stock of the stand; and one record for each measured tally tree. The record of a tally tree contains following data:

- tree species
- tally tree quality class
- d
- $\hat{v}/d^2$
- $\hat{v}_t/d^2$
- $\hat{v}_w/d^2$
- $\hat{i}_v/d^2$.

(Volumes and and growth are divided by d^2 before they are stored in the file in order to decrease the errors due to rounding off).

When area estimates are calculated for different strata, e.g. site classes, the sample point is used as one observation. Area estimates are obtained with Formula (17) (Salminen 1993).

$$\hat{A}_i = m_i/M * AREA, \quad (16)$$

where $\hat{A}_i$ = estimated area for stratum i,

m_i = number of sample points in stratum i,

M = total number of sample points on the land in the calculation area, and

AREA = land area of the calculation area.

Volume sum and mean statistics for a calculation area or different strata of the area are compiled by summing the volumes and plot factors of the plots over the strata in question. The mean volume is calculated by dividing the volume sum by the sum of the plot factors. No mean volumes for single stands of a relascope plot are needed. In fact, it is impossible to calculate such mean volumes in the NFI data for stands that do not cover the whole relascope plot.

In the case of a restricted relascope plot with maximum radius of 12.45 m (as in NFI8 in Kainuu district) the volume sum of a plot (section) is calculated as follows.

$$V = \sum n_j * v_j, \quad (17)$$

where V = volume sum of the plot (section),

$n_j = q*4/\pi *10000/d^2$, if $d_j < 30.5$

20.53579, otherwise

q = basal area factor (BAF)

v_j = volume of a tally tree ($dm^{3)}$

Σ = summation over all trees measured on the plot.

It should be noted, that Formula (17) does not differentiate between whole plots and plots sections. The size of a plot is taken into account later when the means or sums are calculated for the calculation strata.

After the volume sums are calculated for each part plot, mean volume estimates for different strata of a inventory area are obtained with Formula (18).

$$\bar{V}_i = \frac{\Sigma V_i}{\Sigma F_i}, \qquad (18)$$

where $\bar{V}_i$ = estimated mean volume for stratum i,

V_i = volume sum of a plot (section) (see Formula 17), and

F_i = plot factor of the plot (section) i

Σ = summation over all plots in a calcultation stratum of the inventory area.

4. APPLICATION OF THE SYSTEM FOR KAINUU DISTRICT

4.1 Estimated models

The upper diameter functions estimated using sample trees from Kainuu district are in Appendix 2. Separate models were estimated for following species: pine (Pinus sylvestris), spruce (Picea abies), white birch (Betula pendula), silver birch (B. pubescens), aspen (Populus tremuloides), alder (Alnus incana and A. glutinosa). As described earlier, NFI7 data were used as prior information for some of the parameters and only as information for other parameters (Korhonen 1992).

The bark models for sample trees of Kainuu district are in Appendix 3. Separate models for pine, birches (no difference between white and silver birch), aspen and alder were used. The models were estimated using NFI7 and NFI8 sample tree data from Kainuu district.

Volume functions estimated for different species for Kainuu district are in Appendix 4. For pine, spruce and birches the final parameter estimates were calculated separately for 4 site class groups. For aspen, alder and the group of other species the sample tree data were too few to distinguish between site classes. The models presented in Appendix 4 are not logical for small sized trees. Therefore, general volume functions were used for trees with $d < 3$ cm.

The regression models for timber assortmentwise volumes are presented in Appendix 5. The data for pine and spruce were divided into two site class groups. Separate models for timber and cull volume models were estimated for the two groups. The data for birches were too few to make a distinction between site classes. For aspen only few sample trees were coded as timber quality trees, and therefore no model for timber volume were estimated. At the application stage, timber volume model of birches were used for those aspens that were coded as timber quality trees. For other species, no timber trees were measured; models were estimated only for cull volume. The correction factors for timber assortmentwise volumes (see Section 3.2.1) are also given in Appendix 5.

The estimated models for the past 5-year volume growth of different species are in Appendix 6. Separate models for trees growing at forest land and poorly productive land were estimated. For forest land separate models for pine, spruce, birches and aspen were used. For poorly productive land birches and aspen were combined to the group of other species. The correction terms (see Equation (16)) are also given in Appendix 6.

4.2 Examples of calculated statistics for Kainuu district

According to the statistics of the National Board of Survey, the total land area of Kainuu district is 2 156 690 ha. Estimated area of forest land is 1 664 015 ha. Figures 2 and 3 present two examples of estimated percentages of different strata. In Figure 2 is the distribution of forest land by dominant species. Figure 3 presents the age class distribution on the forest land in Kainuu district.

The estimated mean and total volumes and timber assortmentwise mean and total volumes by species on forest land and poorly productive land are given in Table 1. The growth statistics obtained using the calculation system are presented in Table 2.

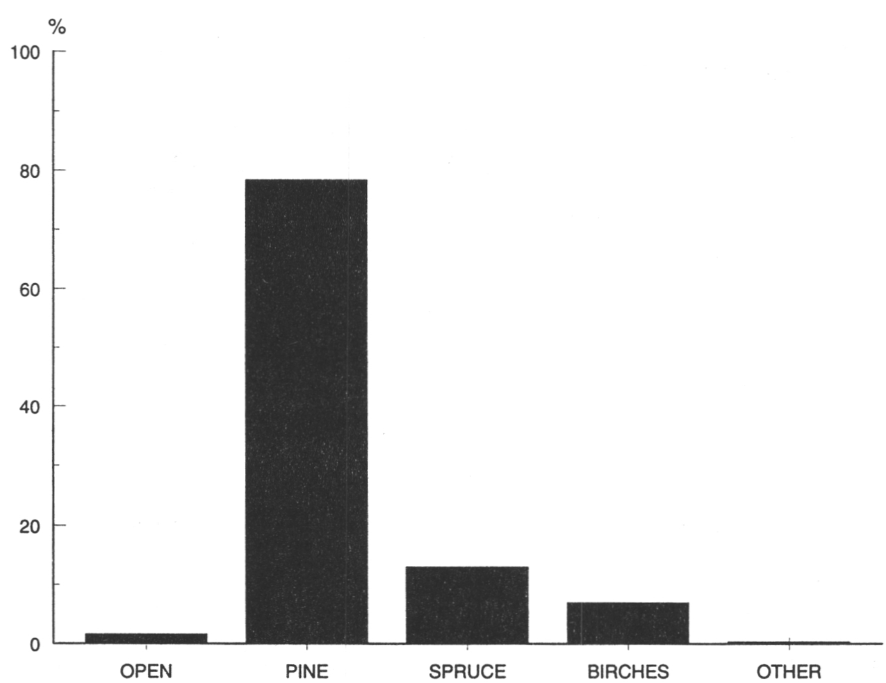


Figure 2. Dominance of tree species on forest land.

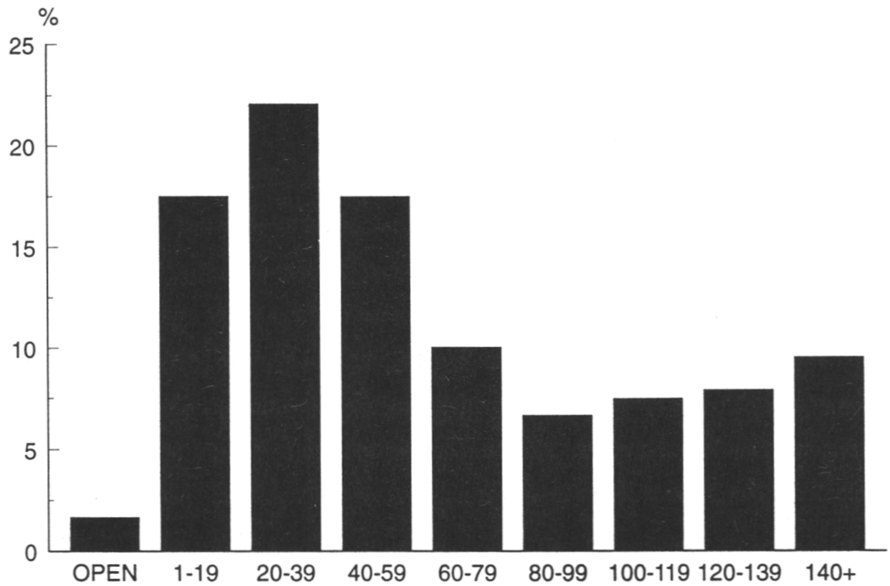


Figure 3. Age structure on forest land

Table 1. Mean and total values of stem volume and timber assortmentwise volumes by species for forest and poorly productive land.

	Mean volumes, m³/ha			Total volumes, 1000 m³		
	saw log	pulp	total	saw log	pulp	total
Pine	13.3	21.9	37.7	25089	41288	71062
Spruce	6.1	9.8	16.9	11427	18427	31947
Birches	0.2	6.2	8.7	414	11763	16382
Others	0.0	0.7	1.1	29	1273	2009
All	19.8	44.8	64.4	36959	72750	121401

Table 2. Mean and total value estimates for growth by species for forest and poorly productive land.

	Pine	Spruce	Birches	Others	All
m³/ha	1.35	0.41	0.38	0.06	2.20
1000 m³	2552	782	715	104	4153

5. DISCUSSION

The system of calculation presented in this paper differs from the present calculation system for NFI in the following ways:

1. Stem volume and the timber assortmentwise volumes are generalized for tally trees using regression models instead of classwise mean values.
2. Growth estimates are calculated for tally trees with a method similar to that for estimating the timber assortmentwise volumes. In the present calculation system growth is not generalized for tally trees (growth is estimated using growth percentages estimated from the sample tree data and diameter distributions estimated from the tally tree data).

The above-mentioned solutions make the system flexible. Area, volume and growth estimates can easily be calculated for any sub-class of the data. Plotwise volume and growth estimates can easily be used as a 'ground truth' for processing satellite images (Tomppo 1992).

Characterics of 'final interest', such as timber assortmentwise volumes and volume growth, were used as dependent variables when the models were estimated from the sample tree data. Another possibility would have been to use variables describing the dimensions (d, d_6, h, b, i_d, i_h) and quality (lengths of different quality classes) as independent variables. The models would then give estimates of all sample tree variables for every tally tree. These estimates could be used as independent variables for further estimations, e.g. of the volume or growth of tally trees. Various modifications of this method described by Kilkki (1979) are widely used in inventory systems. The method has one serious drawback, however: residual variance of the different models must be taken into account when, e.g., using estimated h, i_d, and i_h as independent variables in estimating volume increment (Kilkki 1979). The joint distributions of the errors of the different models are difficult to estimate. Therefore, after some trials this approach was rejected.

As stated, in this system of calculation sample tree variables such as height and age are not generalized for tally trees. Therefore, the data generated for tally trees cannot be used to predict the future development of forests with simulation systems like the Finnish Mela-system (Siitonen 1983). Further studies are needed if, for example, the grid method (Holm et al. 1979) is applicaple for generalizing the sample tree characteristics for tally trees in such a way that the results can be used as a basis both for calculating unbiased inventory statistics and for simulating the future development of the trees.

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Appendix 1. Functions for ratio of volume over bark and cross sectional area inside bark ($r = v/g_i$) (Kujala 1980).

$$r(h) = 0.39 + 0.39*h + 2/(h.1-3) + 0.77*\sqrt{(h-1.3)}$$

$$r(h) = 0.44 + 0.355*h + 2/(h.1-3) + 0.65*\sqrt{(h-1.3)}$$

$$r(h) = 0.48 + 0.48*h + 3.5/(h.1-3)$$

Appendix 2. Upper diameter models for Kainuu district.

Model:

$$\ln(d_6) = a_0 a0 + a_1 * d2 + a_2 * h2 + a_3 * t + a_4 * d/t + a_5 * \ln(\hat{d}_{6L}) +$$
$$a_6 * \ln(G) + a_7 * YC + a_8 * YC2 + a_9 * XC + a_{10} * XC2 +$$
$$+ a_{11} * YC * XC$$

Parameters:

	Pine	Spruce	White birch	Silver b.	Aspen	Alder
a_0	-0.0721	0.0659	0.0602	0.2173	0.0191	-0.0829
a_1	-4.684E-5	7.169E-5	-2.857E-6	1.278E-4	1.246E-5	1.148E-4
a_2	1.489E-4	-8.169E-5	8.577E-5	2.375E-4	1.324E-4	-1.100E-4
a_3	1.281E-4	-1.115E-4	-3.214E-4	-4.367E-4	-0.1201	2.168E-3
a_4	-0.1182	-0.0746	-0.1000	-0.3855	-	0.1436
a_5	1.0081	0.9588	0.9534	0.9473	0.9874	0.9308
a_6	-1.147E-3	9.742E-3	0.1471	-0.0463	-0.2063	0.0358
a_7	0.0941	0.1476	-	-	-	-0.0261
a_8	-2.964E-3	-0.2212	-0.0836	-0.0289	0.0764	0.2898
a_9	0.0942	0.0421	0.2444	-0.1988	0.2153	-0.2811
a_{10}	-5.546E-3	-0.0658	-0.1121	0.2827	-0.3818	0.5933
a_{11}	-0.1076	0.0351	-0.2176	0.2297	0.1430	-0.6086
Correction terms for anti-logarithm transformation						
	.0034	0.0042	0.0049	0.0097	0.0086	0.0086

Appendix 3. Bark models for Kainuu district.

Pine
Model:
$b = a_0 + a_1*d + a_2*h$

Parameters:

Pine	
a_0	2.437408
a_1	1.070841
a_2	-0.213063

Other species:

Model:
$\ln(b) = a_0 + a_1*\ln(d) + a_2*\ln(h)$

Parameters:

	Spruce	Birches	Aspen	Alder	Others
a_0	0.632961	0.127477	-0.058233	0.172857	-0.246579
a_1	1.021860	1.037599	1.012449	0.807302	1.107772
a_2	-0.323278	-0.175557			
Correction terms for anti-logarithm transformation	0.026473	0.052313	0.047472	0.068787	0.066722

Appendix 4. Volume models for Kainuu district

Model:

$$v/d2 = a_0 + a_1*d + a_2*d2 + a_3*RDIST + a_4*\ln(G) + a_5*YC + a_6*YC2 + a_7*XC + a_8*XC2 + a_9*XC*YC$$

Parameters:

Pine

	Site 1	Site 2	Site 3	Site 4
a_0	-0.1757	-0.1249	-0.0712	0.0441
a_1	0.0264	0.0238	0.0198	0.0146
a_2	-2.825E-04	-2.164E-04	-1.377E-04	-4.935E-05
a_3	0.0879	0.0761	0.0666	0.0353
a_4	-0.0720	-0.0720	-0.0720	-0.0720
a_5	0.0249	0.0249	0.0249	0.0249
a_6	-0.0167	-0.0167	-0.0167	-0.0167
a_7	0.3726	0.3726	0.3726	0.3726
a_8	-0.2197	-0.2197	-0.2197	-0.2197
a_9	-0.2476	-0.2476	-0.2476	-0.2476

Spruce

a_0	-0.0893	3.115E-03	0.0237	0.1862
a_1	0.0327	0.0286	0.0265	0.0155
a_2	-3.967E-04	-3.216E-04	-3.720E-04	-3.144E-05
a_3	0.0618	0.0405	0.0401	-4.315E-03
a_4	-0.0557	-0.0557	-0.0557	-0.0557
a_5	0.0392	0.0392	0.0392	0.0392
a_6	-0.1380	-0.1380	-0.1380	-0.1380
a_7	0.2755	0.2755	0.2755	0.2755
a_8	-0.3008	-0.3008	-0.3008	-0.3008
a_9	-0.2573	-0.2573	-0.2573	-0.2573

Birches

a_0	0.0343	0.0449	0.1013	0.1421
a_1	0.0194	0.0150	0.0130	0.0117
a_2	-1.476E-04	-2.589E-05	-1.084E-05	9.621E-05
a_3	0.0449	0.0477	0.2686	3.202E-03
a_4	-0.0343	-0.0343	-0.0343	-0.0344
a_5	0.0289	0.0289	0.0289	0.0289
a_6	0.0191	0.0191	0.0191	0.0191
a_7	0.5617	0.5617	0.5617	0.5617
a_8	-0.3332	-0.3332	-0.3332	-0.3332
a_9	-0.6914	-0.6914	-0.6914	-0.6914

Appendix 4 continues...

Aspen, all site classes

a_0 0.1148
a_1 0.0247
a_2 -3.010E-04
a_3 -
a_4 0.0208
a_5 0.0169
a_6 0.1352
a_7 0.3626
a_8 -0.0835
a_9 -0.8237

Other species, all site classes

a_0 0.1893
a_1 6.795E-03
a_2 -1.286E-04
a_3 -
a_4 3.807E-03
a_5 0.0793
a_6 -0.2261
a_7 0.2853
a_8 -0.3899
a_9 -1.1990

Appendix 5. Models for timber assortmentwise volumes for Kainuu district.

Model:

Timber volume
$vt/(10*d2) = a_0 + a_1*ln(d) + a_2*DD$

Cull volume
$vw/(10*d2) = a_0 + a_1*ln(d) + a_2*DD$

Total volume
$vt/(10*d2) = a_0 + a_1*ln(d) + a_2*DD$

Parameters

Pine, non-timber trees

	Site 1 and Site 2			Site 2 and Site 3		
	Timber	Cull	Total	Timber	Cull	Total
a_0		-2.740E-3	-0.0182		-3.447E-3	-0.0180
a_1		0.0663	0.0233		0.0713	0.0223
a_2		5.418E-6	1.065E-04		3.961E-6	6.580E-05

Pine, good quality timber trees

	Site 1 and Site 2			Site 2 and Site 3		
	Timber	Cull	Total	Timber	Cull	Total
a_0	-0.0572	5.122E-4	-4.881E-3	-0.0633	8.366E-4	0.0168
a_1	0.0351	4.687E-3	0.0232	0.0357	-2.816E-3	0.0254
a_2	1.764E-04	2.539E-6	9.187E-5	1.553E-4	2.465E-6	8.462E-5

Pine, poor quality timber trees

	Site 1 and Site 2			Site 2 and Site 3		
	Timber	Cull	Total	Timber	Cull	Total
a_0	-0.0116	-9.316E-4	3.245E-3	-0.0325	-1.3096E-3	-0.0301
a_1	0.0146	0.0537	0.0199	0.0196	0.0559	0.0291
a_2	1.292E-4	6.058E-6	9.331E-5	8.893E-5	5.5309E-6	9.981E-5

Spruce, non-timber trees

	Site 1 and Site 2			Site 2 and Site 3		
	Timber	Cull	Total	Timber	Cull	Total
a_0		-2.460E-3	-0.0271		-3.640E-3	-0.0137
a_1		0.0654	0.0274		0.0796	0.0207
a_2		7.298E-6	7.031E-5		5.179E-6	6.134E-5

Spruce, good quality timber trees

	Site 1 and Site 2			Site 2 and Site 3		
	Timber	Cull	Total	Timber	Cull	Total
a_0	-0.1240	-3.500E-4	-0.0231	-0.1054	7.606E-4	-0.0169
a_1	0.0550	0.0242	0.0277	0.0476	-3.107E-3	0.0241
a_2	7.424E-5	9.236E-7	7.394E-5	7.313E-5	1.154E-6	7.060E-5

Spruce, poor quality timber trees

	Site 1 and Site 2			Site 2 and Site 3		
	Timber	Cull	Total	Timber	Cull	Total
a_0	-0.0404	-3.026E-3	4.054E-3	0.0342	-1.478E-3	0.0529
a_1	0.0231	0.1066	0.0185	-1.041E-3	0.0708	1.734E-3
a_2	1.335E-4	5.733E-6	6.860E-5	9.959E-5	7.944E-6	8.710E-5

Appendix 5 continues...

Birches, non-timber trees

	Site 1 and Site 2			Site 2 and Site 3		
	Timber	Cull	Total	Timber	Cull	Total
a_0		-8.520E-4	-0.0206		-6.973E-4	-0.0159
a_1		0.0574	0.0248		0.0570	0.0212
a_2		2.476E-5	7.342E-5		3.493E-5	5.192E-5

Birches, good and poor quality timber trees

	Site 1 - 4		
	Timber	Cull	Total
a_0	1.069E-3	1.091E-3	0.0490
a_1	0.0108	-2.698E-3	3.270E-3
a_2	1.036E-4	3.038E-6	6.943E-5

Aspen

	Site 1 - 4		
	Timber	Cull	Total
a_0		1.049E-3	-0.0109
a_1		0.1044	0.0214
a_2		1.972E-4	5.124E-5

Alder

	Site 1 - 4		
	Timber	Cull	Total
a_0		4.753E-3	0.0179
a_1		0.0360	7.404E-3
a_2		8.392E-5	5.452E-5

Other species

	Site 1 - 4		
	Timber	Cull	Total
a_0		0.0189	0.0274
a_1		-0.1023	-5.770E-4
a_2		1.458E-4	1.264E-5

Correction terms

	Pine	Spruce	Birches	Aspen	Alder	Others
timber	0.952	0.939	0.781	0.681		
cull	0.994	0.975	0.963	0.989	0.985	0.949

Appendix 6. Volume growth models for Kainuu district.

A. Forest land

Model:

$$\ln(iv/d2) = a_0 + a_1*d + a_2*\ln(d) + a_3*G + a_4*DD + a_5*D/T + a_6*S0 + a_7*S1 + a_8*S2 + a_9*S3 + a_{10}*SOIL$$

Parameters:

	Pine	Spruce	Birches	Aspen	Others
a_0	-4.3044	-6.3137	-5.5625	-1.6637	-1.5368
a_1	-0.0526				
a_2	0.4547	0.1150	-0.1783	-0.4314	-0.4879
a_3	-0.0312	-0.0195	-0.0403		
a_4	1.1839	2.8326	3.2296		
a_5	1.8928	3.5339	2.5957		
a_6	0.6923	0.4706	0.6429		
a_7	0.6100	0.4047	0.2326		
a_8	0.5005	0.4047	0.1427		
a_9	0.3282	0.3782			
a_{10}	-0.1210	-0.3810	0.2448		

Correction terms

Pine	1.086
Spruce	1.140
Birches	1.073
Aspen	1.045
Others	1.372

B. Poorly productive land

Model:

$$\ln(iv/d2) = a_0 + a_1*\ln(d)$$

Parameters:

	Pine	Spruce	Others
a_0	-2.3182	-3.0830	-1.7185
a_1	-0.3738	-0.3218	-0.6303

Correction terms

Pine	1.360
Spruce	1.004
Others	1.360

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