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National forest inventory of Finland and its role estimating the carbon balance of forests

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The paper presents the total stem volume increment and total drain, as well as the corresponding carbon contents, of the trees of Finnish forests. The carbon contents are converted to carbon dioxide equivalents. The total increment is above stump stem wood volume increment including bark. The estimates come from the National Forest Inventory of Finland conducted by the Finnish Forest Research Institute. The method is briefly described. The total drain includes fellings, i.e. removals and cutting waste, as well as natural mortality of above stump stem wood volume of trees including bark. The above stump stem volumes are converted to total tree biomass, total dry matter and total carbon content using available coefficients.
Keywords. National Forest Inventory, increment, carbon content, Finland.

1. THE NATIONAL FOREST INVENTORY OF FINLAND

Finnish forests have been measured by National Forest Inventories (NFI) eight times. The first inventory was carried out in 1921–1924 and the eighth one in 1986–1994. In 1994, the oldest part of the data was updated by remeasuring 38% of the field plots in South Finland. The field measurements of the updated eighth inventory thus come from the years 1989-94 (Tomppo, Henttonen 1996). The NFI9 began in 1996.

The NFI is a sampling based inventory. Field plots are located on clusters (**Figure 1**). The sampling design has been fitted to the variability of land use classes and variation of the structure of the growing stock in different parts of the country. The distance between two clusters in Central Finland in NFI9 was 7 km (**Figure 1**). The distance between two field plots in a cluster was 300 m. Every fourth cluster consisted of permanent plots (14 plots) and other of temporary plots (18 plots). The field plots 11–14 are not measured on the permanent plots (**Figure 1**). Thus, about one fifth of the field sample plots have been established permanently. Re-measurements of the permanent sample plots provide information concerning those changes in trees and forests which cannot be easily assessed by means of temporary field plots, e.g. changes in site fertility and natural mortality of trees. Increment borings are carried out only on temporary plots. The permanent plots, together with new temporary plots will be utilised in the increment estimation in the coming inventories.

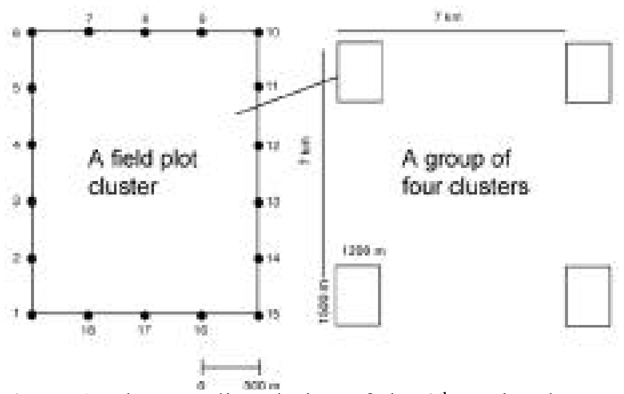

Figure 1. The sampling design of the 9th National Forest Inventory (NFI9) in Central Finland. Three of four clusters consist of temporary plots (18 plots) and one is established permanently (14 plots, the plots 11–14 are not measured).

The workload of NFI8 was:
– over 70,000 field plots on forestry land;
– over 150 characteristics measured or assessed;
– half a million tallied trees (tree species, diameter, timber assortment class and its precision as well as crown layer are measured);
– every 7th tree was measured in more detail, e.g. height, diameter and height increments and age, health and timber assortments (**Figure 2**).

The workload of NFI9 will be similar when the whole country has been measured, in 2003.

The measured characteristics include information about, e.g., soil, site fertility, structure and amount of growing stock of trees, tree growth, damage, accomplished and necessary silvicultural- and cutting measures and indicators of the biological diversity of forests. The inventory results concerning growing stock, its structure and increment, as well as the forest condition, have been employed in forest management planning,

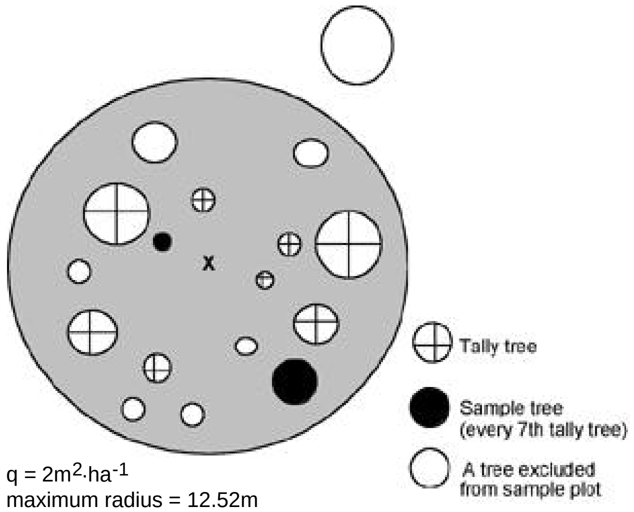

Figure 2. The field sample plot of the 9th National Forest Inventory (NFI9) in Central Finland. There are 10 tally trees of which 2 are sample trees.

planning of forest industry, nature conservation, as well as in analysing the long-term changes of forests.

The field data are used to estimate statistics on forest resources for large areas, such as Forestry Centres. The sampling intensity has been designed in such a way that estimates of forest area and volume of growing stock are reliable for areas larger than 200,000–300,000 ha (**Figures 1** and **2**).

A multi-source inventory method has been developed to produce forest resource information for small areas, e.g. municipalities, as well as thematic maps. Satellite images and other geo-referenced data are employed, such as digital maps, in addition to the field data. Landsat TM or Spot -images are currently employed (Tomppo, 1991).

2. THE ESTIMATION OF THE INCREMENT OF THE GROWING STOCK AND ITS RELIABILITY

The increment of the growing stock of trees is estimated using field measurements from sample plots. The measurements are carried out at two different levels of intensity, at tally tree level and sample tree level (**Figure 2**). A few characteristics, e.g. diameter, tree species, timber assortment class and canopy layer class, are measured for tally trees, while more characteristics are measured for sample trees, e.g. upper diameter, height, diameter and height increments. Volumes and volumes five years ago are computed for sample trees using taper curve models and estimated volume per basal area ratio curve as a function of tree height (Laasasenaho, 1982; Kujala, 1980). Volumes are estimated for tally trees using a non-parametric regression method (Tomppo *et al.*, 1997; Tomppo *et al.*, 1998). Volume increments are estimated for tally trees by computation strata and by diameter classes using the average 5-year increments of the sample trees of the stratum and the numbers of tally trees in the stratum. The annual increment is simply the 5-year increment divided by 5. The volume increment of the trees which have been removed or died during the increment estimation period (5-year period) is estimated using the annual drain estimates, see later, and the increment ratio of the drain and survived trees (Salminen, 1993). The final total increment is the increment of the survived trees plus the increment of the drain.

The reliability of the estimates of the NFI is computed following the ideas presented by Matérn (1960). The relative standard error of the volume increment of the growing stock in the 8th inventory and its updating (1989–1994) was 0.8% (Tomppo, Henttonen, 1996). The 95% confidence interval for increment of 75.4 Mm^3 is 74.2 Mm^3, 76.6 Mm^3. The confidence intervals for carbon (C) uptakes or releases cannot be computed in a reliable way due to the fact that the reliability of the coefficients given in Karjalainen, Kellomäki (1996) is unknown. These coefficients are used in converting the tree stem volume to total tree biomass.

The total annual drain estimate of forests is based on the statistics of cutting removals reported by forest industry companies, the estimates of the household use of timber based on enquiries, the estimate of the cutting waste obtained from timber assortment quality requirements and taper curve models. The volume of natural losses has earlier been estimated using a study by Kuusela *et al.* (1986). The current estimate has been derived from the 3000 permanent field plots and is 2.5 Mm^3. An analytical expression for the reliability of the total drain is not available. The reported statistics of cutting removals are considered to be reliable.

3. EXAMPLES OF THE TIMBER AND CARBON BALANCE FIGURES

The reporting of greenhouse gases (GHG) related to forests differs from the instructions of Intergovernmental Pannel on Climate Change (IPCC, 1996). The above stump tree stem volume increment and drain are estimated as given above and converted to total tree biomass, total dry matter and total C- content using coefficients given by Karjalainen and Kellomäki (1996). The conversion equation is:

$$cf = ef \cdot dw \cdot cc \quad (1)$$

where
cf = conversion factor from stem volume to total biomass C-content,
ef = expansion factor from stem volume to total tree biomass
dw = conversion factor to dry matter
cc = C-content.

The values of the components are given in **table 1**. The conversion factors depend on the site fertility and age structure of forests. However, the same factors have been used in national reporting for reasons of compatibility. More accurate, age structure dependent factors are going to be developed in the future. The problem is that the age structure of drain is not known. It can, however, be estimated from the NFI.

The stem volume increments in the NFI are computed as an average of the increments of the inventory year and four years previous to the inventory (as mean of the five years preceding the inventory up to July 31) (Kuusela, Salminen, 1969). The inventory proceeds by region and the increment figures for the entire country come from different years. The inventory has lasted 5 to 10 years. The inventory results are updated only through field measurements, not e.g. with models and simulations. Modelling presumes annual increment variation measurements each year in the whole country. These are not carried at the moment. The trend-like changes in the stem volume growth are no longer as high as they were in the 1970s and 1980s, so the increments given in the **table 2** are relatively up-to-date. The inventory years for the increment figures for 1995 and 1999 are, for example:
– 1995: 1989–1994,
– 1999: 1992–1999.

Table 1. The coefficients *dw ef* and *cc* according to Karjalainen, Kellomäki (1996).

	dw (Mg·m^{-3})	*ef*	*cc*	*cf* (Mg·m^{-3})
Pine	0.390	1.527	0.519	0.3091
Spruce	0.385	1.859	0.519	0.3715
Non-coniferous	0.490	1.678	0.505	0.4152

The drain figures correspond exactly to the given year. A small difference in C-change between **table 2** and that given by Karjalainen *et al.* (1996) is caused by the difference in the total increment; a slightly smaller increment figure has been used in this latter article.

The C-balance of 1990 is presented in two different ways (**Table 2**). The first one is based on the same increment calculation method as for the years 1991–1999. The second one is based on a computational updating of the increment figures, i.e. on a forecast of the increment, carried out only once, so far, by the NFI. The real increment turned out to be smaller when the actual measurements were made. The reason for giving the 1990 figures based on the computational updating is that the corresponding CO_2 net emission has already been reported (Karjalainen *et al.*, 1996).

The net emissions of CO_2 to be reported, e.g., in the Summary Report for National Greenhouse Gas Inventories, are the figures of the last (right hand) column of **table 2**. The figure of 23.8 Mt for 1990 is compatible with the other figures for the years 1991–1999.

Table 2. Stem volume increment and drain, as well as C- and carbon dioxide uptake and release of trees from 1990 to 1999.

	Volumes (Mm^3)			C (Mt)			CO_2 (Mt)		
Year	Increment	Drain	Balance	Uptake	Release	Balance	Uptake	Release	Balance
1990	73.4	55.1	18.3	26.2	19.7	6.5	95.9	72.1	23.8
1990[1]	79.0	55.1	23.9	28.0	19.7	8.3	102.6	72.1	30.4
1991	74.3	44.6	29.7	26.4	16.0	10.4	96.8	58.6	38.2
1992	75.8	51.0	24.8	26.9	18.2	8.7	98.6	66.7	31.9
1993	76.6	53.8	22.8	27.2	19.2	7.9	99.5	70.4	29.1
1994	75.4	61.6	13.8	26.7	22.0	4.7	97.8	80.6	17.3
1995	75.4	63.6	11.8	26.7	22.7	4.0	97.8	83.1	14.7
1996	75.5	59.0	16.5	26.7	21.0	5.7	98.0	77.0	21.0
1997	75.9	65.8	10.1	26.9	23.4	3.4	98.6	85.9	12.6
1998	77.2	69.4	7.8	27.3	24.7	2.6	100.1	90.4	9.7
1999	78.0	69.4	8.6	27.6	24.7	2.9	101.3	90.4	10.8

[1] computational forecast of the increment of the growing stock.

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